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System Status Display Evaluation

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SUMMARY

The System Status Display Study is part of the Advanced Transport Operating Systems Program sponsored by the National Aeronautics and Space Administration's Langley Research Center and is directed toward the development of advanced display information for the flight deck operations of future commercial aircraft. The system status display (SSD) is an electronic display system which provides the crew with an enhanced capability for monitoring and managing the aircraft systems and which may be used in a standalone mode or in conjunction with automated system control. The benefits of this system include improving the crew's interaction with the aircraft systems, improving the reliability of crew and system operations, and ensuring efficient use of flight deck workspace.

This report presents the results of the second part of the study. The objective was to evaluate alternative design concepts developed in the first part. The evaluation was by flight simulation in a fixed-base flight deck simulator. Design issues included:

1. Display Format — Should the status information be presented in a pictorial format or alphanumeric text?
2. System Control — Are multifunction controls collocated with system status information better than dedicated controls separated spatially from status information?
3. Procedural Information — Does the integration of procedural information with system status information improve crew performance over the use of paper checklist with the status information?

The SSD consisted of computers, a color CRT, a display control panel, system interfaces with the systems, and either dedicated or multifunction control panels. The SSD was used in conjunction with a master caution and warning system based upon the guidelines proposed by the Alerting Systems Standardization Study.¹ The simulation implemented models of the SSD, alert, fuel, and hydraulic systems as well as the aerodynamics and equations of motion of a large-body transport aircraft,

Twelve pilots with extensive commercial jet transport experience participated in the study. The simulation trials were conducted with a single pilot per trial. The other pilot was assumed to be incapacitated to simulate a high workload. While the pilot manually flew an approach pattern, system malfunctions caused alerts. The pilot was required to respond to the alert by reconfiguring the system.

Performance measurements consisted of (1) the time required to acknowledge the alert, (2) the time required to complete the abnormal procedures, (3) the number of discrete steps to complete the procedures, and (4) the number of errors committed. Flight performance and the amount of flight control activity were measured to determine the effect of the experimental conditions on the primary flight task. A modified Cooper-Harper rating scale was used to measure subjective workload.

With pictorial displays, significantly less time was required to complete the abnormal procedures, and there was a lower workload score. It was concluded that pictorial displays are superior to text for the presentation of system status information. The multifunction control interfaces collocated with the status information had shorter completion times and lower workload scores than the dedicated overhead panel. It was concluded that the collocation of the controls with the status information was the primary reason.

The interactive procedure information had shorter completion times, less discrete steps, and fewer errors than the paper checklists. One drawback to the use of interactive procedures was that the pilots tended to react only to the procedures without full comprehension of the problem or the consequences of their actions. The experimental conditions had little impact upon the primary flight activity.

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INTRODUCTION

BACKGROUND

Current transport aircraft use multifunction color CRTs to display engine and aircraft status information. The first study² identified principles and guidelines to be used in the design of display formats for the management and control of aircraft systems. A system engineering approach was used to identify and classify information requirements for various aircraft systems according to flight phase. This approach permitted the identification of information based upon the crew's requirements for decision making and performing actions. The information was partitioned into four distinct classes: (1) identifiers, (2) descriptors, (3) status, and (4) instructions. This classification helps identify information sources and the grouping of that information.

One issue that remained was the display format. Should the display format be pictorial or alphanumeric text? Several studies have developed pictorial schematics for aircraft systems' displays.^{2,3,4,5} These studies were of conceptual designs and none was concerned with comparative evaluations of other concepts or current displays. The first operational transport aircraft to use pictorial schematics and checklists on CRTs for the aircraft systems is Airbus Industries' A310. These aircraft are in active use which proves the concepts are feasible. However, it remains to be shown that pictorial schematics are improvements over other display concepts, including alphanumeric text.

A review of the cognitive literature implies that pictures are better than words for aircraft systems' displays. Pictures are recognized faster than words, but it takes longer to name pictures than words.⁶ This may be due to the memory coding of pictures and words. Pavio^{7,8} proposed that pictures are stored in direct memory which has a close relationship to the sensory experience that created the image. Words are stored in phonemes (speech utterances) or the visual representation of phonemes. Communication or comparison of pictures or a sensory experience to words is by way of the short-term working memory.

Another factor is the retention of an aircraft system in long-term memory. Chase⁹ suggests that the memory of a system is an abstraction of the spatial and the functional relationships of objects to one another. Egam and Schwartz¹⁰ in their study of circuit diagrams concluded that experts recall patterns based on their conceptual knowledge of a circuit's function. These studies suggest that the crew retention of an aircraft system in long-term memory would be similar to the functional schematic. They further suggest that less mental steps are required to extract information from a pictorial schematic than from a word listing.

Another issue for the SSD concept is the control interface with the aircraft systems. Are multifunction controls acceptable or should dedicated controls be retained? If dedicated controls are used, they must be separated from the multifunction display. In transport aircraft, the only reasonable location for dedicated controls is in the overhead panel, and the only reasonable location for the SSD is in the center instrument panel. Multifunction controls, (e.g., line select keys or touch panels) can be collocated with the SSD. This confounds the issue; if multifunction controls are used, they can be collocated with the SSD while dedicated controls must be separated spatially.

Two options for the multifunction controls were considered for this study: (1) line select keys, and (2) a touch panel overlay. Line select keys are mounted on the CRT bezel with a line pointing to the component that they activate. These are currently being used with flight management computer's control display units. The problem with these keys is that they are separated from the displayed information. With a touch panel overlay, the control and information source are coincident. Although touch panels have advantages, there are also some disadvantages.¹¹ These include the virtual area and separation of the keys on the display, separation of the touch panel from the phosphor surface of the CRT which

causes a parallax problem, the requirement for feedback other than tactile, the smudging of the display surface, and vibration caused by normal aircraft operation.

Another potential control interface is voice-activated controls. The primary advantage of voice control is that it does not require hand coordination and movement. It requires speech utterances so that the same problems with alphanumeric text will occur with voice control. Other problems are recognition reliability and transmission time.¹² Because of these drawbacks, voice control was not considered in this study.

A separate issue involved with aircraft systems control is automation. With the new-generation flight decks such as those on the Airbus A320 and the MD-11, on-line monitoring and reconfiguration are being automated. This eliminates the need for the crew to monitor and control the systems; the crew only provides a backup when the automated system fails. This has raised concerns about flight safety; e.g., the ability of the crew to recognize and respond to failures of the automatic system and also, how the crew can maintain its skill level to provide this manual backup.^{13, 14} The issues include what information should be provided for crew monitoring of the automated functions and how information should be provided for manual backup.

SYSTEM STATUS DISPLAY CONCEPT

A system status display (SSD) was developed³ to evaluate these issues in a simulation study. The SSD consisted of computers, color CRT displays, display control panels, I/O interfaces with the aircraft systems, and control interfaces for systems control. A block diagram of the system is shown in Figure 1.

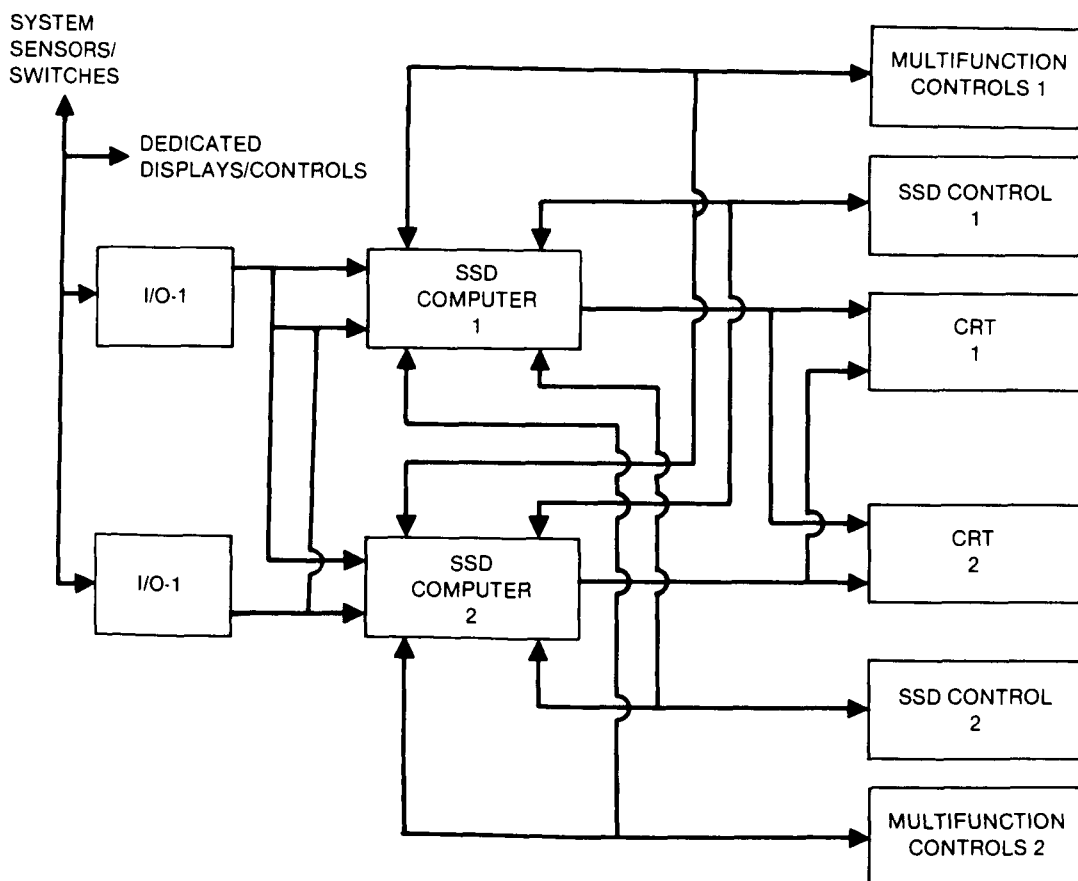


FIGURE 1. SYSTEM ARCHITECTURE OF THE SYSTEMS STATUS DISPLAY.

Each aircraft system may have its own independent control units that provide fault monitoring, detection, and correction. The prioritization and display of alerts were provided by a master caution and warning (MCW) system. The MCW consisted of redundant computers, the MCW annunciators, aural tones, and the alert display. The MCW was designed according to the guidelines set forth by the FAA Alerting Systems Standardization Study.¹

The SSD computer generates status display formats, stores and presents procedures, monitors crew actions, and prompts the crew. The system provides the crew with feedback on the results of its actions and annunciates changes in aircraft status and operating characteristics. The SSD provided information for operation of the aircraft systems both when the primary mode of operation was manual or when manual operation was the backup to automated system control.

Using the SSD, the following issues were addressed:

1. Display Format — Should the aircraft status information be presented in pictorial schematics or alphanumeric text?
2. System Control — Are multifunction controls with system status information better than dedicated controls separated spatially from status information?
3. Procedure Information — Does the integration of procedural information with system status information improve crew performance over the use of paper checklist with the status information?

The objective of this study was to use the SSD on a fixed-base simulator to resolve these issues. Both objective performance measures and pilot opinion were used to evaluate the results.

METHOD

PILOTS

Twelve pilots from Douglas Aircraft Company's Flight Operations department participated in this study. These pilots averaged 6,800 hours in commercial jet transport aircraft and all but one had more than 500 hours in DC-10 aircraft. The balance of their flight time was in DC-8, DC-9, MD-80, 727, C-5A and C-130 aircraft. The pilots' mean age was 57 years, their median age was 58, and their ages ranged from 33 to 67.

EXPERIMENTAL DESIGN

A full factorial repeated-measures design was used for the two display formats, the three control interfaces, and the two procedural presentations. The pilots were divided into two groups. One group received the interactive procedures in the first block of trials and the paper checklist in the second block. The other group received the opposite. The display formats and the control interfaces were counter-balanced within the block of trials so that each pilot received a unique sequence of conditions. There were two trials for each of the experimental conditions. Within each trial, three non-normal events occurred. These events prompted advisory, caution, and warning alerts requiring the pilot response while flying the aircraft.

SIMULATOR

A fixed-base cockpit simulator, shown in Figure 2, was used for the evaluation. This is a modified DC-10 cockpit with computer-driven displays, a programmable McFadden center-stick controller, rudder



FIGURE 2. FIXED BASE COCKPIT SIMULATOR.

pedals, a throttle quadrant, slat/flap controls, and a landing gear handle. The primary flight instruments are electromechanical. Two 8-inch color CRT displays were mounted in the center instrument panel for the SSD, the engine, and the alert displays. The aircraft and system models are provided by a DEC VAX 8600 computer. The VAX 8600 was linked to a satellite computer that serves as an input/output interface to the controls, the instruments, and the visual terrain model. The SSD model and displays are provided by the VAX 8600 linked to a Vector General graphics system that drives the two Xytron CRT displays. The graphic system is a calligraphic or stroke written system.

The simulation consists of several models which interact with each other as shown in Figure 3. The equations of motion, the aerodynamics, the controls, and the engine models are based on a two-engine DC-10. The fuel and hydraulic system models are simplified operating models that provide system status information for the SSD and inputs for the engine and control models.

The fuel model supplies manifold pressure for the engines and the consumption of fuel depends on their thrust settings. Loss of fuel pressure would produce a caution alert but would not cause the engine to flame out. The hydraulic model supplies manifold pressure for the hydraulic actuators on the control surfaces. The loss of hydraulic pressure in one of the manifolds results in the loss of the actuators supplied by the manifold which may affect the controllability of the aircraft. The state of the fuel and hydraulic systems depend upon the switch settings and system malfunctions introduced as part of the event scenario. Descriptions of these systems are contained in Appendix A.

STATUS DISPLAY SYSTEM

The SSD is the left CRT display in the center instrument panel (Figure 2). It has multiple pages which contain phase-of-flight and system-status information. The selection of the pages depends on the phase of flight, an alert, or pages can be manually selected via the SSD control panel located in the pedestal. The information on the pages depends on the status of the systems. The page formats include phase-of-flight pages and system pages. The system pages consist of formats with varying levels of detail.

The SSD control panel, shown in Figure 4, is located on the left side of the pedestal aft of the throttle quadrant. This panel consists of backlighted pushbutton switches. The crew can select either the phase-of-flight, the fuel, the hydraulic, or the flight control surface pages. Page advance and backpage switches are provided to select the alternate pages within a system.

MASTER CAUTION AND WARNING SYSTEM

The alerting system uses the guidelines developed by the FAA Alerting System Standardization Study.¹ It consists of a MCW annunciator on the glareshield, aural tones, and an alert display that occupies the left portion of the right CRT in the center instrument panel. The alert display contains text annunciations of the alerts in their associated color (warning — red, caution — amber, and advisory — cyan) and ordered according to alert level. The alerts are ordered chronologically within an alert level with the most recent at the top of the list. The syntax is the system name, the specific subsystem, and the nature of the problem. The sequence of events depends on the alert level as follows:

Warning

When a warning occurs, the master warning annunciator on the glareshield turns on and the warning tone sounds. The warning tone is an alternating high- and low-frequency tone lasting one second and sounds every three seconds until the pilot cancels it with the annunciator switch. A red alert message appears on the alert display and remains for the duration of the problem. The associated system page appears on the SSD until the problem is resolved or the pilot manually selects another page.

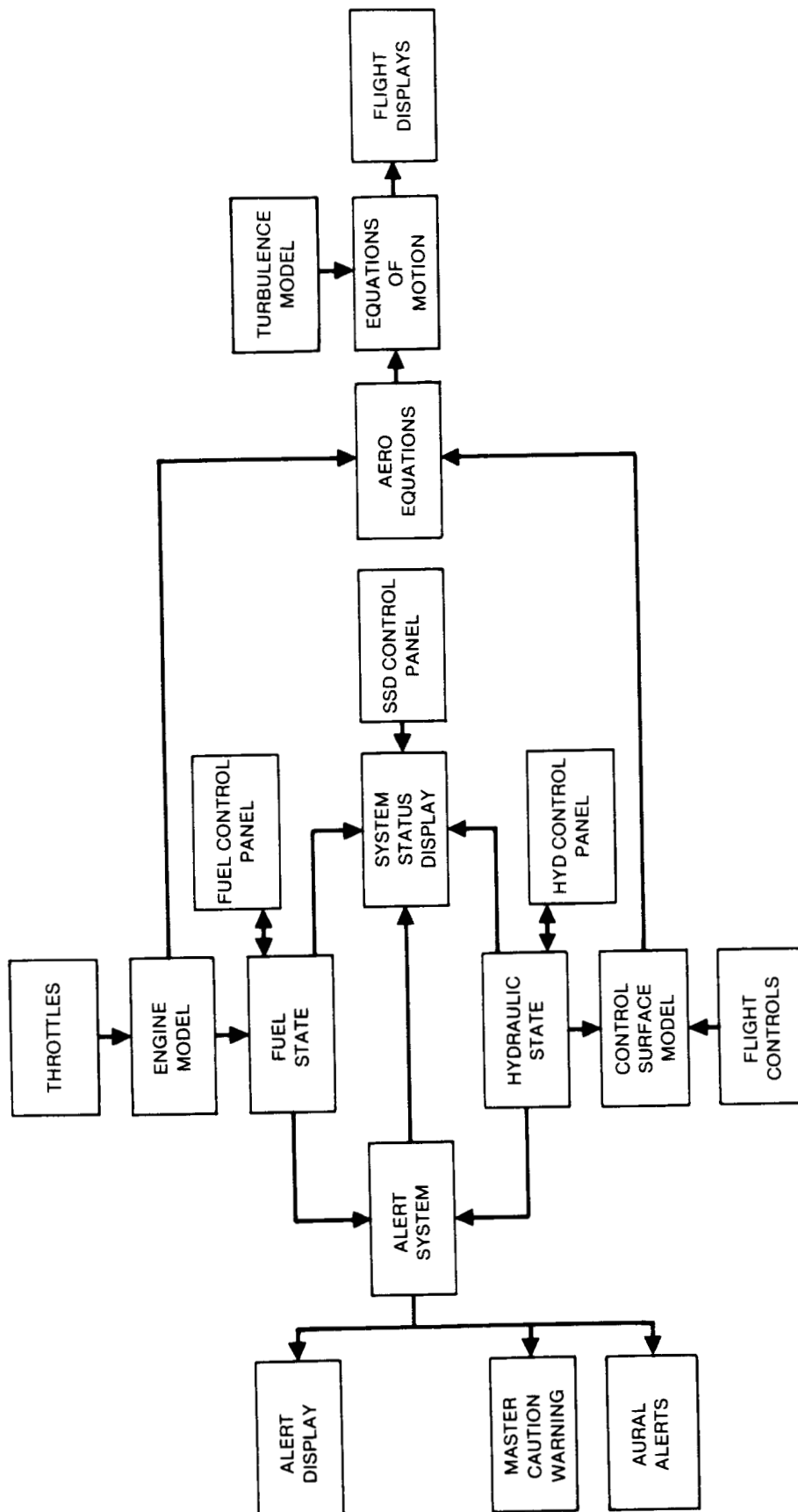


FIGURE 3. SYSTEM DIAGRAM OF THE SSD SIMULATION.

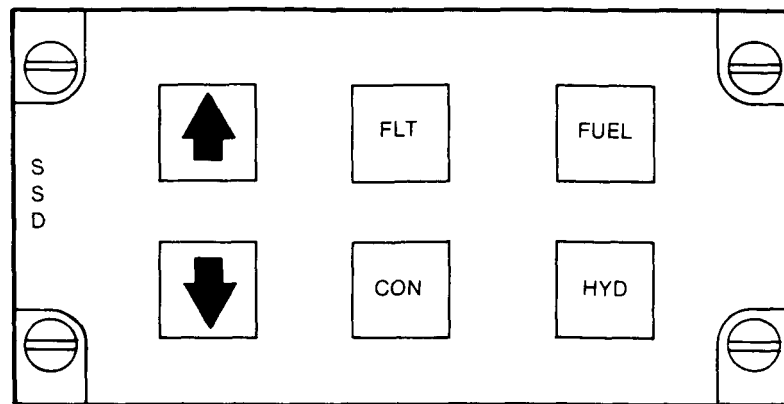


FIGURE 4. SSD CONTROL PANEL LOCATED IN CENTER PEDESTAL.

Caution

When a caution occurs, the master caution annunciator on the glareshield turns on, and a steady tone that lasts for one second sounds; the tone is repeated every 10 seconds until the pilot cancels it with the annunciator switch. An amber alert message appears below any warnings on the alert display which remains displayed until the problem is corrected. The system page associated with the alert is displayed until the problem is resolved or the pilot manually selects another page.

Advisory

When an advisory occurs, a single tone sounds which is similar to a chime and a cyan alert message appears on the alert display below the caution messages. The existing system page remains on the SSD until the crew selects the appropriate page.

EXPERIMENTAL VARIABLES

The issues enumerated in the INTRODUCTION were the display format, the system control interface, and the presentation of procedural information. The following variables were selected for the evaluation.

System Display Format

Two format conditions were selected: (1) pictorial, and (2) alphanumeric text. Examples of these formats are shown in Figures 5 and 6 for the hydraulic system. The formats for the fuel, hydraulic, and control surfaces are presented in Appendix B. The following general rules were used to develop these formats.

Pictorial — The overall structure of the display is a schematic of the system and is representative of the physical orientation in the aircraft and the functional relationship of the systems and their elements. Pictographs are used for the components and parallel lines connecting the pictograph elements are manifolds. The fill between these lines represents the operational state of the system. If empty, the system is off; if filled green, the system is operating normally; and if filled in an alert-level color, the system is non-normal. Alphanumerics are used as labels. Quantitative information is shown by analog scales as well as numerics.

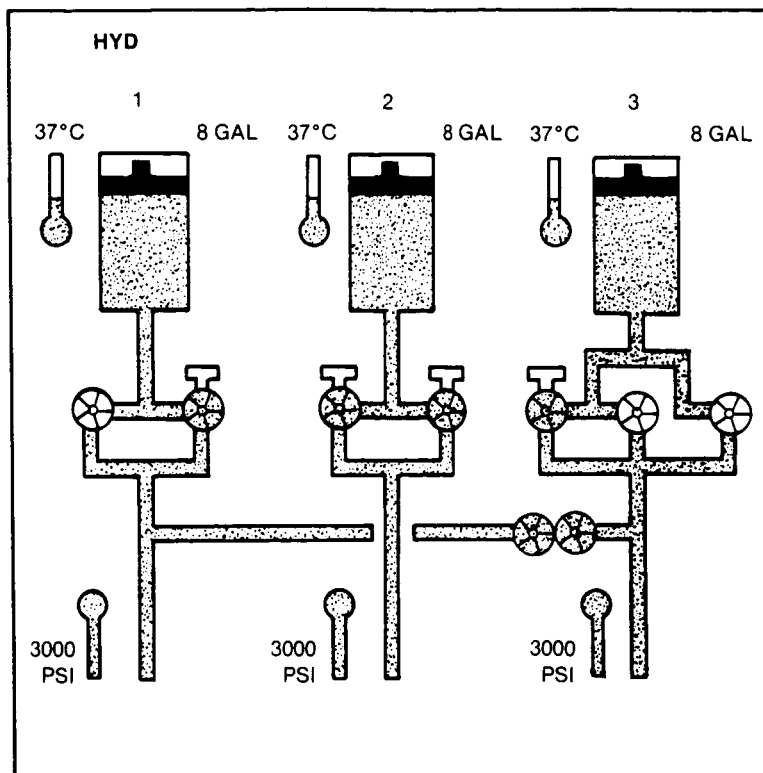


FIGURE 5. PICTORIAL SCHEMATIC OF HYDRAULIC SYSTEMS PAGE

HYD		
QUANTITY	QUANTITY	QUANTITY
8 GA	8 GA	8 GA
TEMP	TEMP	TEMP
37 C	37 C	37 C
PRESSURE	PRESSURE	PRESSURE
3000 PSI	3000 PSI	3000 PSI
E1 PUMP	E1 PUMP	E2 PUMP
ON	ARMED	ON
AUX PUMP	E2 PUMP	AUX PUMP
OFF	ON	OFF
	MTR PUMP	RAT
	ARMED	OFF

FIGURE 6. ALPHANUMERIC TEXT OF HYDRAULIC SYSTEMS PAGE

Alphanumeric Text — The names of the system components are used to identify them. As in the pictorial schematic, the names are grouped according to their physical orientation as well as the functional relationships.

Adverbial phrases are used to describe the status of a system component. The color of the adverbial phrase indicates whether it is off (grey), operating normally (green), or is in an abnormal state (red, amber or cyan). Numerics are used to show quantitative information.

System Control

Three methods of controlling the fuel and hydraulic systems were provided: a dedicated overhead panel, a touch panel overlay on the SSD, and line select keys mounted on the SSD bezel.

Dedicated Overhead Panel — The overhead panel consists of a backlighted panel with split-legend push-button switches. The switches are laid out in a schematic diagram with flow lines representative of manifolds connecting the switches. A diagram of the overhead panel is shown in Figure 7. The switch shows a lighted flow line if it is operating normally, unlighted if it is off, and an annunciation if it is in a non-normal state. Also, low system pressure annunciations are provided.

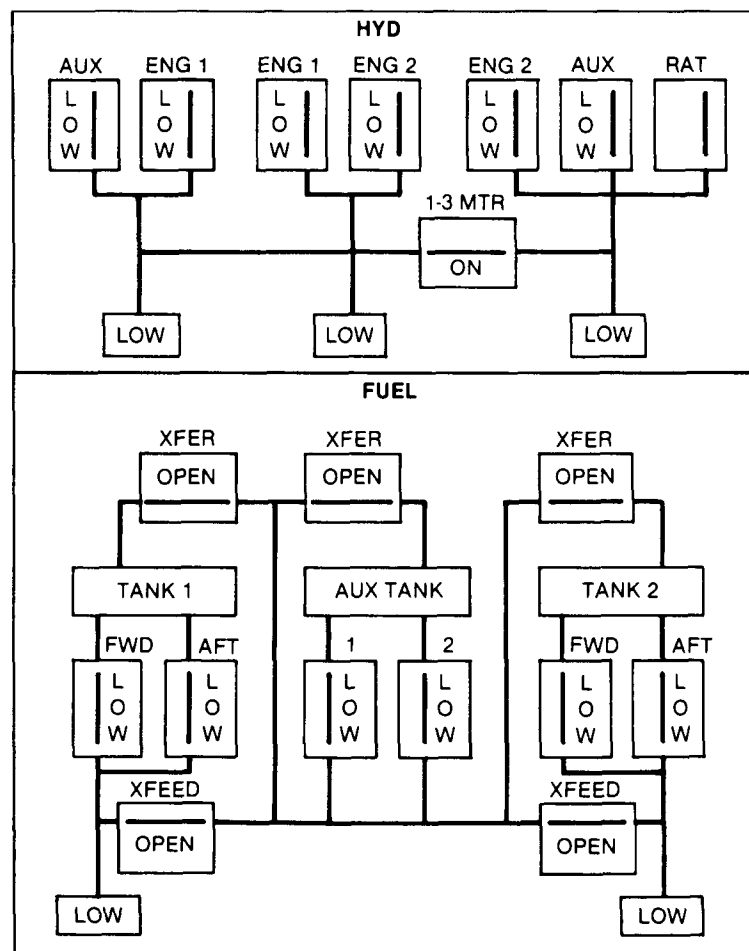


FIGURE 7. DEDICATED OVERHEAD PANEL FOR FUEL AND HYDRAULIC SYSTEMS.

Line Select Keys — The bezel-mounted keys consist of illuminated pushbutton switches. Dashed lines are provided on the SSD to show which key is associated with what component on the status display. Figure 8 shows an example of the line select keys with the fuel schematic. Feedback is provided by tactile means and by a change in component status on the SSD.

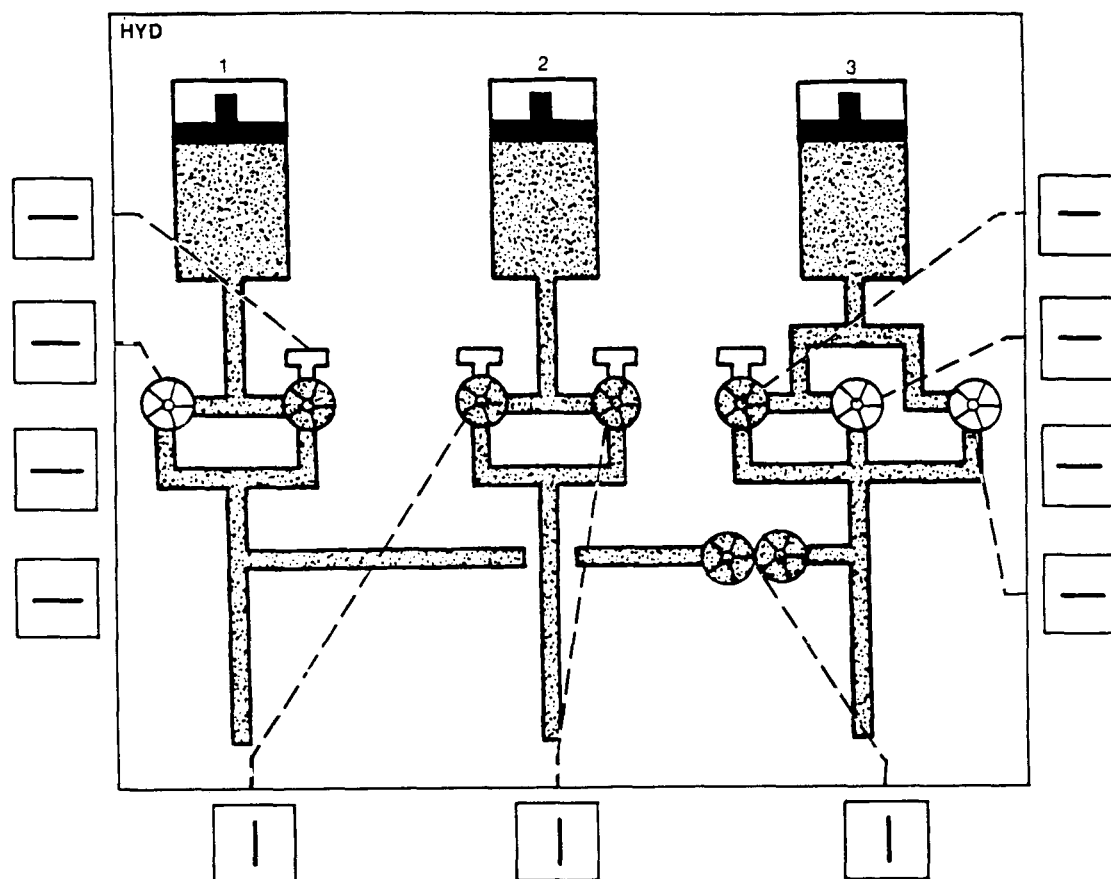


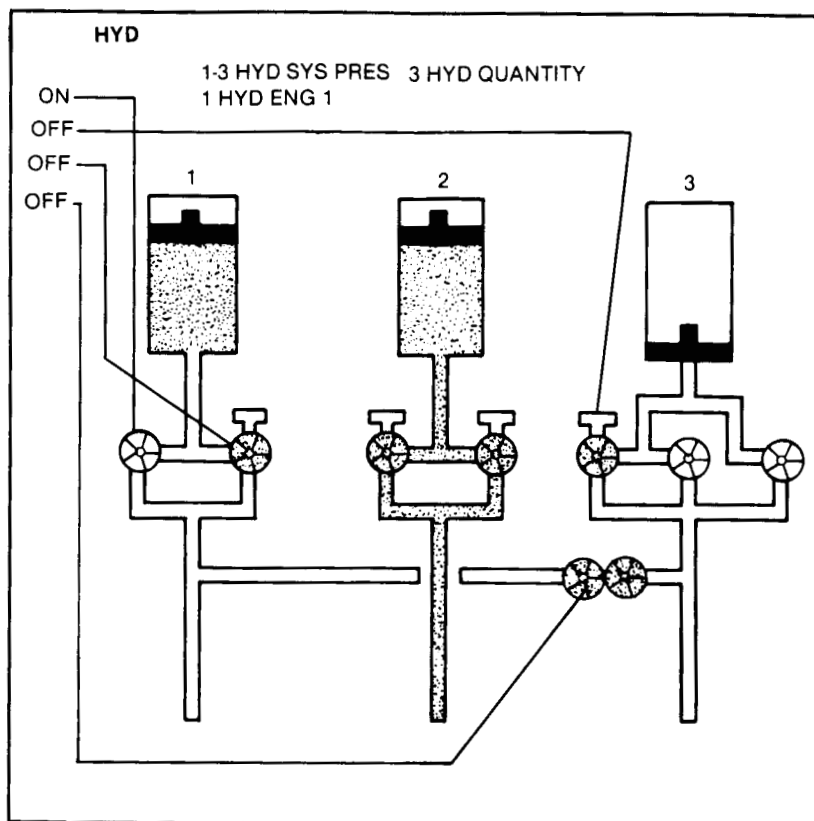
FIGURE 8. LINE SELECT KEYS ASSOCIATED WITH THE FUEL DISPLAY.

Touch Panel — A membrane touch panel manufactured by Elographics, Inc. was mounted over the SSD. The virtual area of the switch was a half-inch square centered over the component symbol or alphanumeric text. Feedback was provided by a half-second tone and a change in component status on the SSD.

Procedure Information

The procedure information consisted of the identification of the component to be changed and the action to be taken. Two methods of presenting this information were evaluated: (1) interactive procedures on the SSD, and (2) the use of a paper checklist.

Interactive Procedures — The procedure format depended upon the display format. If the SSD format was pictorial, the adverb associated with the action and an arrow pointing to the component was displayed on the SSD. If there were more than one action required, a list of actions would appear on the left side of the display. For the alphanumeric text, the component name and the action adverb were listed at the top of the display. These two presentations are illustrated in Figure 9. The color of the procedures



HYD

1-3 HYD SYS PRES	3 HYD QUANTITY
1 HYD ENG 1	
1 HYD AUX.....	ON
3 HYD ENG 2.....	OFF
1-3 MOTOR PUMP.....	OFF
1 HYD ENG 1.....	OFF

QUANTITY	QUANTITY	QUANTITY
8 GA	8 GA	0 GA
TEMP	TEMP	TEMP
37 C	37 C	37 C
PRESSURE	PRESSURE	PRESSURE
0 PSI	3000 PSI	0 PSI
E1 PUMP	E1 PUMP	E2 PUMP
ON	ARMED	ON
AUX PUMP	E2 PUMP	AUX PUMP
OFF	ON	OFF
	MTR PUMP	RAT
	ARMED	OFF

FIGURE 9. INTERACTIVE PROCEDURES FOR THE PICTORIAL AND TEXT DISPLAYS.

is magenta and the current procedure is brighter than the remainder. If the crew member performs the procedure, it is deleted from the display. If the fault is not corrected or an incorrect action occurs, new procedures appear depending upon the system state.

Paper Checklist — The other method was a paper checklist equivalent to the abnormal checklist used in current commercial transports or the quick reference handbook. An example of the checklist is shown in Figure 10. The entire checklist used in this study is presented in Appendix C. For each fault there is a list of procedures where the components and the action adverbs are listed. The checklist has decision branches where the crew must determine the state of the system or aircraft before deciding which branch to take.

Procedure

The pilots were scheduled for three 3-hour sessions. The first session was the briefing and a practice session and the remaining two were data sessions. The experimenter read the briefing to the pilot and answered any questions. The pilot briefing is presented in Appendix D. After completing the briefing, the pilot was given six practice trials, one on each of the display format/control interface combinations for the first procedure presentation condition. The experimenter assisted the pilot in performing the system functions to accelerate the pilot's learning. In the second session, the pilot was given two trials on each of the six conditions for the first procedure presentation condition. In the third, he received two trials on each of the six conditions for the second procedure presentation condition. After completing all three sessions, the pilots filled out the questionnaire that is contained in Appendix E.

FUEL SYSTEM PRESSURE LOW (C)		APPROACH		3 HYD SYSTEM PRESSURE (C)	
FORWARD PUMP	ON	FLAPS/SLATS	EXTEND	IF QUANTITY IS OK,	
IF PRESSURE REMAINS LOW,		IF FLAPS/SLATS DO NOT MOVE,		RAM AIR TURBINE	UNLOCK
1 & 2 XFEED	OPEN	AIR SPEED	REDUCE	OTHERWISE,	
1 & 2 XFER	CLOSE	FLAPS/SLATS	15/EXT	ENG PUMP	OFF
FUEL QUANTITY	MONITOR	IF FLAPS/SLATS DO NOT MOVE,		AUX PUMP	OFF
		Q/RET LDG	PERFORM	MTR PUMP	OFF
FUEL CONFIGURATION (A)		IF ONLY FLAPS MOVE,		CONTROLLABILITY	REVIEW
IF FUEL IN AUXILIARY TANK,		FLAPS/SLATS	22/EXT	APPROACH	
AUXILIARY PUMP	ON	22/RET LDG	PERFORM	FLAPS/SLATS	EXTEND
LO TK XFER VALVE	OPEN	OTHERWISE,		IF FLAPS/SLATS DO NOT MOVE,	
HITK XFER VALVE	CLOSE	FLAPS/SLATS	35/EXT	AIR SPEED	REDUCE
WHEN BALANCED,		IF SLATS RETRACT,		FLAPS/SLATS	15/EXT
HITK XFER VALVE	OPEN	FLAPS/SLATS	22/EXT	IF FLAPS/SLATS DO NOT MOVE,	
NO FUEL IN AUXILIARY TANK		22/EXT LDG	PERFORM	Q/RET LDG	PERFORM
HITK FWD PUMP	ON	OTHERWISE,		IF ONLY FLAPS MOVE,	
HITK XFER VALVE	CLOSE	35/EXT LDG	PERFORM	FLAPS/SLATS	22/EXT
HITK XFEED	OPEN			22/RET LDG	PERFORM
WHEN BALANCED,		2 HYD SYSTEM PRESSURE (C)		OTHERWISE,	
HITK XFEED	CLOSE	ENG PUMPS	OFF	FLAPS/SLATS	35/EXT
HITK FWD PUMP	OFF	CONTROLLABILITY	REVIEW	IF SLATS RETRACT,	
1 HYD SYSTEM PRESSURE (C)		APPROACH		FLAPS/SLATS	22/EXT
ENG PUMP	OFF	FLAPS/SLATS	EXTEND	22/EXT LDG	PERFORM
AUX PUMP	OFF	IF FLAPS DO NOT MOVE,		OTHERWISE,	
MTR PUMP	OFF	Q/EXT LDG	PERFORM	35/EXT LDG	PERFORM
CONTROLLABILITY	REVIEW				

FIGURE 10. EXAMPLE OF PAPER CHECKLIST.

With a two-person flight crew, the pilot not flying operates the aircraft systems. However, for this evaluation it was assumed that the first officer was incapacitated, and the captain flew the aircraft and operated the systems. This simulates the worst-case condition and increases the pilot's workload. The pilot flew the aircraft with manual throttles and the flight director in moderate turbulence. The simulator did not have glareshield controls so that the pilot could not enter the heading, vertical-speed and altitude-select values. The experimenter, on cue from the computer program, acted as the ATC operator and gave the pilot vectors and clearances. Ten seconds after the computer cued the experimenter, the select values were entered into the guidance commands by the computer program.

The initial conditions simulated an altitude of 7,000 feet, a heading of 360 degrees, and an airspeed of 220 knots. The experimenter instructed the pilot to descend to 4,000 feet and slow to 190 knots. When the aircraft leveled off at 4,000 feet, the pilot was instructed to turn either to 330 or 030 degrees. After completing the turn, the pilot was instructed to descend and maintain 1,500 feet at 170 knots, and he was cleared to intercept the ILS. The trial ended at the time the pilot intercepted the glideslope. The total time of the trial was approximately nine minutes.

Three non-normal events were inserted into the scenarios at given time intervals. The time intervals were from 75 to 200 seconds for the first event, 200 to 350 seconds for the second, and 350 to 500 seconds for the third. These time intervals were selected so that one event would not interfere with the next event, and the pilot would not anticipate the exact time the event would occur. The event types and the alert levels were confounded with the experimental conditions. Also, the alert levels were nested within the event types and there was an unequal number of types for each alert level. The different non-normal events are listed in Table 1. There was a total of 18 scenarios with different combinations of non-normal events. For each condition, a pilot would receive one of the first six scenarios on his first trial and one of the last twelve on the second trial. Therefore, the first six event scenarios were repeated twice per pilot and the last twelve only once. Two of the first six-event scenarios contained three advisories, three scenarios contained two advisories and one caution, and one scenario contained one advisory and two cautions. For the last twelve scenarios, three scenarios contained two advisories and one caution, two scenarios contained one advisory and two cautions, and six scenarios contained one advisory, one caution and one warning. Therefore, each pilot received a total of 42 advisories, 26 cautions, and 6 warnings. The order in which the pilots received the event scenarios was counterbalanced between the pilots.

When an alert occurred, the pilot was instructed to cancel the MCW annunciator, if necessary, and identify the alert on the alert display. He would call up the system page on the SSD, if necessary, to identify and recognize the fault. If he had the interactive procedures, he would identify the corrective action on the SSD and perform the actions with the system controls. If he had the paper checklist, he would look up the fault, identify the actions on the checklist, and perform the actions. After performing the actions, he would verify the system status using the SSD. If he had lost a hydraulic system, he was instructed to call up the control surface status page to review the operability of the aircraft.

Performance Measures

After completing each trial, the pilot was asked to rate workload involved in the task. A modified Cooper-Harper rating scale referred to as the Bedford scale¹⁵ was used for workload ratings. The reasons for selecting this scale were ease of application and pilot familiarity with the Cooper-Harper handling quality rating scale. In addition, the modified Cooper-Harper rating scale appears to be sensitive to differences in pilot workload.^{16, 17, 18}

TABLE 1
NONNORMAL EVENTS

ADVISORY ALERTS

1. FUEL CONFIGURATION — TANK IMBALANCE WITHOUT FUEL IN THE CENTER TANK AND MAY OCCUR WITH EITHER WING TANK. THIS SCENARIO STARTS WITH ONE WING TANK WITH LESS FUEL THAN THE OTHER AND WITH THE LOW TANK ENGINE BURNING FASTER THAN THE OTHER TO CREATE AN IMBALANCE. THE PILOT IS REQUIRED TO TRANSFER FUEL FROM ONE TANK TO THE OTHER AND STOP TRANSFER WHEN THEY ARE BALANCED.
2. FUEL CONFIGURATION — TANK IMBALANCE WITH FUEL IN CENTER TANK AND MAY OCCUR WITH EITHER WING TANK. THIS IS SIMILAR TO NO. 1 EXCEPT THERE IS FUEL IN THE CENTER TANK AND THE CENTER TANK PUMPS ARE OFF. IT REQUIRES THE PILOT TO TURN ON A CENTER TANK PUMP AND OPEN THE APPROPRIATE WING TANK FILL VALVE.
3. HYDRAULIC SYSTEM 1 OR 3 ENGINE PUMP PRESSURE — THIS MAY OCCUR WITH THE ENGINE PUMPS ON SYSTEMS 1 AND 3 AS LONG AS THE REVERSIBLE MOTOR PUMP IS ON. CORRECTIVE ACTION IS TO TURN THE MOTOR PUMP ON AND THE AFFECTED PUMP OFF.
4. HYDRAULIC SYSTEM 2 ENGINE PUMP 2 PRESSURE — THIS OCCURS IF ENGINE 1 PUMP IS ARMED, AND THE ONLY ACTION REQUIRED IS TO TURN OFF ENGINE PUMP 2.
5. HYDRAULIC SYSTEM QUANTITY — THIS MAY OCCUR IN ANY OF THE THREE HYDRAULIC SYSTEMS. CORRECTIVE ACTION IS TO TURN THE AFFECTED PUMPS OFF, BUT EVEN SO, IT IS FOLLOWED BY LOW SYSTEM PRESSURE (CAUTION).

CAUTION ALERTS

6. FUEL LOW PRESSURE — THIS IS CAUSED BY LOW AFT PUMP PRESSURE WITH FORWARD PUMP NORMALLY OFF AND CAN OCCUR WITH EITHER WING TANK. CORRECTIVE ACTION IS TO TURN THE FORWARD PUMP ON.
7. FUEL LOW PRESSURE — THIS IS WITH BOTH FORWARD AND AFT PUMPS FAILED AND MAY OCCUR WITH EITHER WING TANK. CORRECTIVE ACTION IS TO CROSSFEED FUEL.
8. HYDRAULIC SYSTEM FAILURE — THIS MAY OCCUR WITH ANY OF THE THREE SYSTEMS. IT MAY BE CAUSED BY LOW QUANTITY OR THE LOSS OF ALL PUMPS ON A SYSTEM. THE ONLY CORRECTIVE ACTION IS TO TURN OFF THE AFFECTED PUMPS. LOSS OF A HYDRAULIC SYSTEM MAY AFFECT THE CONTROL RESPONSE OF THE AIRCRAFT OR DEPLOYMENT OF A SECONDARY SURFACE.

WARNING ALERT

9. DUAL HYDRAULIC FAILURE — THIS MAY OCCUR WITH ANY COMBINATION OF TWO SYSTEMS. THE ONLY CORRECTIVE ACTION IS TO TURN OFF THE AFFECTED PUMPS. THE CONTROL RESPONSE AND DEPLOYMENT OF THE SECONDARY CONTROL SURFACES IS AFFECTED.

A time-event record of all the discrete events was made and placed into a data file. These events included simulated ATC directives, alert annunciations, and all discrete actions performed by the pilot including secondary control actions, MCW cancellations, SSD control actions, and system control actions. This record was analyzed to determine the following:

1. Alert Acknowledgment Time — The time between the alert annunciation and the MCW cancellation or, in the case of advisories, the SSD page selection.
2. Abnormal Procedure Completion Time — The time between the MCW cancellation or the SSD page selection and the completion of all the system actions.
3. Number of Discrete Actions to Complete the Procedure — The number of discrete actions the pilot completed to process an alert.
4. Procedure Errors — The discrete actions on the time-event record were reviewed by the experimenter who divided each event occurrence into four categories: (1) the pilot performed the procedures according to the interactive list or the paper checklist, (2) the pilot completed the procedures but did not follow the interactive procedures or the checklist, (3) the pilot completed the procedures but made errors in the process, and (4) the pilot failed to complete the procedures.
5. RMS Tracking Errors — RMS tracking errors were measured for those parameters that were to be held steady for a flight segment. These included heading while the aircraft was not turning, vertical speed while the aircraft was descending, and airspeed. These values were measured and recorded at five-second intervals. A 20-second window at the time the events occurred was used to evaluate the tracking performance. This was based upon selecting a time window shorter than the average event processing time.
6. Control Activity — The control activity included the number of times the pilot changed the direction of the primary flight controls; i.e., elevator, ailerons, and rudder and the number of times he hit the pitch trim button. The total number of counts were analyzed for the same 20-second window that the tracking errors were analyzed.

RESULTS

A within-group, repeated measures Analysis of Variance (ANOVA) test was used to analyze the parametric measures, and the Chi Square test was used for the contingency analysis of the correct responses. The treatment conditions were the two display formats, the three control interfaces, the two types of procedure information, the order of the two trials, and the order of the two events within a trial.

An attempt was made to determine if the event-type or the alert-level influenced performance. However, as mentioned in the procedure, the event-type and its alert-level were confounded with the other experimental conditions. Two separate, one-way ANOVA tests were used to analyze the measures by event-type and alert-level. However, alert-level was nested within event-type and there were an unequal number of event-types within each alert-level category. If the alert-level was significant, then separate ANOVAs were performed for event-types within an alert-level. If there were no significant differences within an alert-level, it was assumed that the alert-level contributed to the differences in performance.

ACKNOWLEDGMENT TIME

A summary of the significant ANOVA results for acknowledgment time are presented in Table 2. The complete ANOVA tables for all the experimental results are presented in Appendix F. Table 2 shows that the type of procedure information, the trial order, the event order and their first order interactions were significant. Both alert-level and event-types are significant, which may be responsible for the differences in the trial and event order. The average detection times for type of procedure information are shown in Figure 11. The differences between event-types are shown in Figure 12. There were no significant differences between event-types within the advisory or the caution-alert levels. Figure 12 shows that detection time was longer for advisory-alerts than either the caution- or warning-alerts.

TABLE 2
SUMMARY OF ACKNOWLEDGMENT TIME ANOVAs

VARIABLE	DEGREES OF FREEDOM	F RATIO	PROBABILITY
PRIMARY VARIABLES (IF P > 0.05 THE VARIABLE IS NOT LISTED)			
PROCEDURE	1,11	13.01	0.01
TRIAL	1,11	11.99	0.01
EVENT	1,11	19.60	0.001
PT	1,11	5.33	0.05
PE	1,11	10.39	0.01
TE	1,11	8.89	0.01
ALERT LEVEL			
ALERT	2,22	12.89	0.001
EVENT TYPE			
TYPE	8,88	6.57	0.001
ADVISORY EVENTS			
TYPE	4,44	2.01	0.10
CAUTION EVENTS			
TYPE	2,22	1.20	0.30

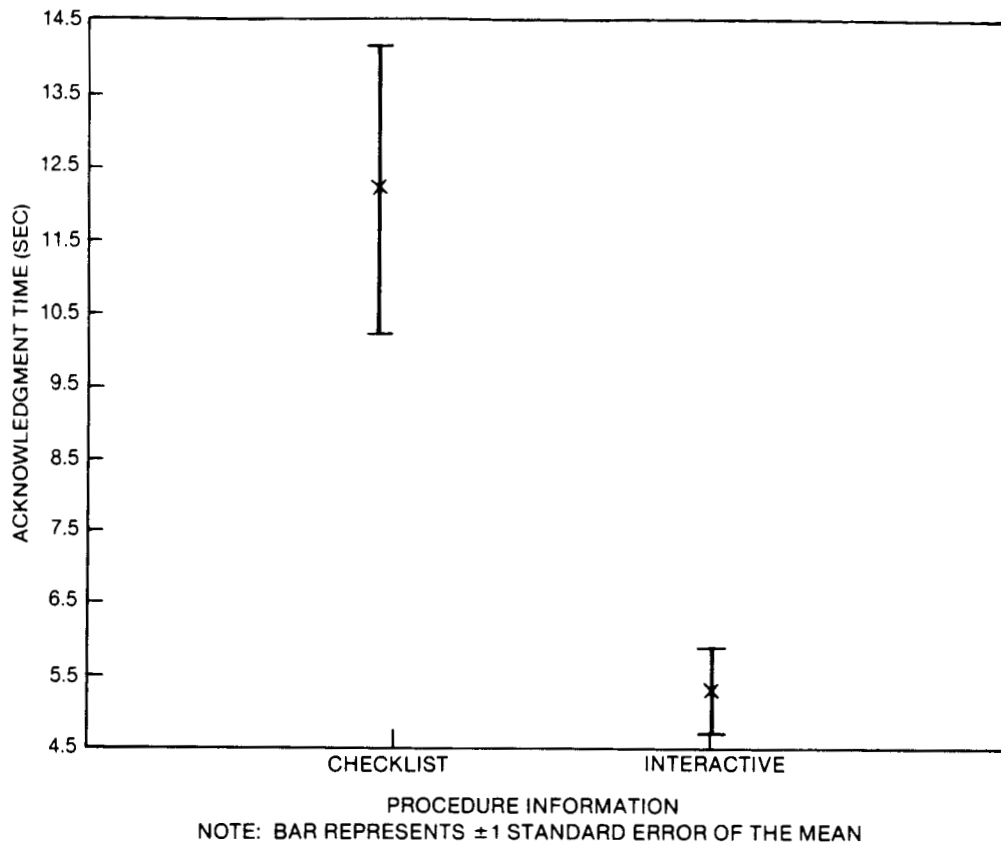


FIGURE 11. ACKNOWLEDGMENT TIMES AVERAGED ACROSS PILOTS FOR TYPE OF PROCEDURE INFORMATION.

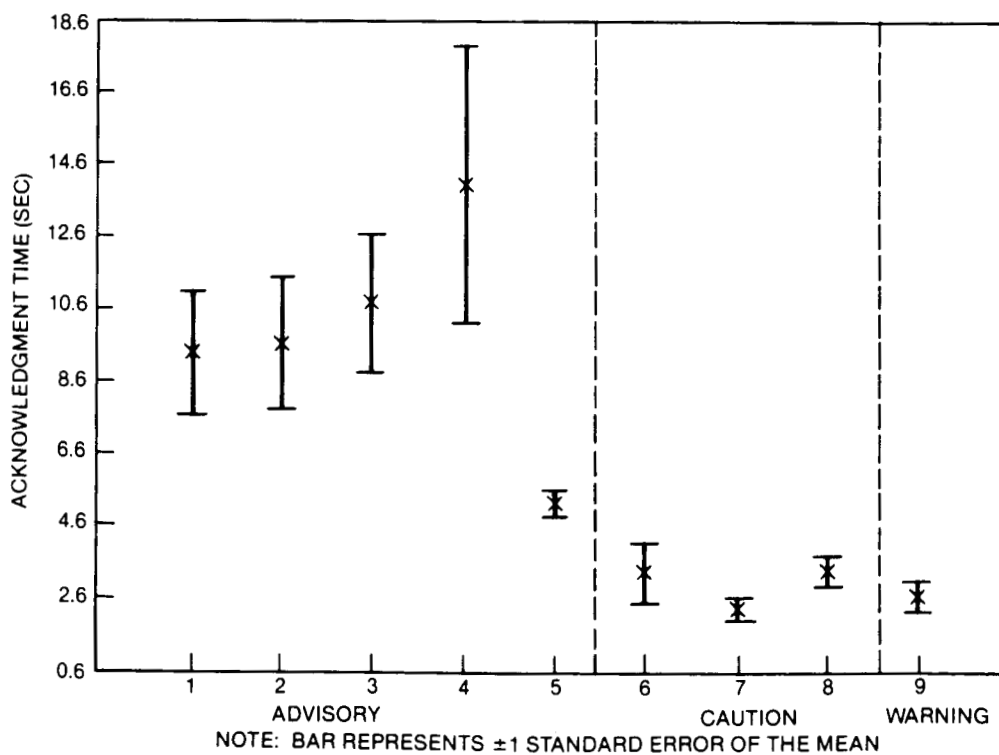


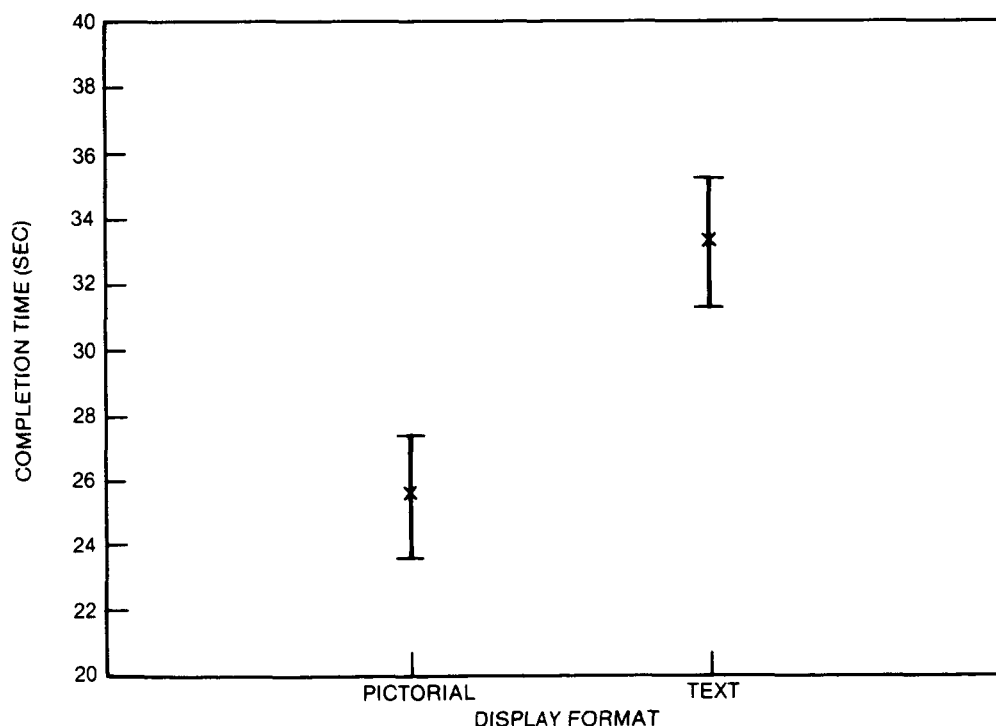
FIGURE 12. ACKNOWLEDGMENT TIME AVERAGED ACROSS PILOTS FOR EVENT TYPE.

COMPLETION TIME

The ANOVA results for the completion time are presented in Table 3 which shows that display format and procedure information were very significant while the control interface was significant. These differences are illustrated in Figures 13 to 15. Figure 13 shows that, on the average, text takes 1.3 times

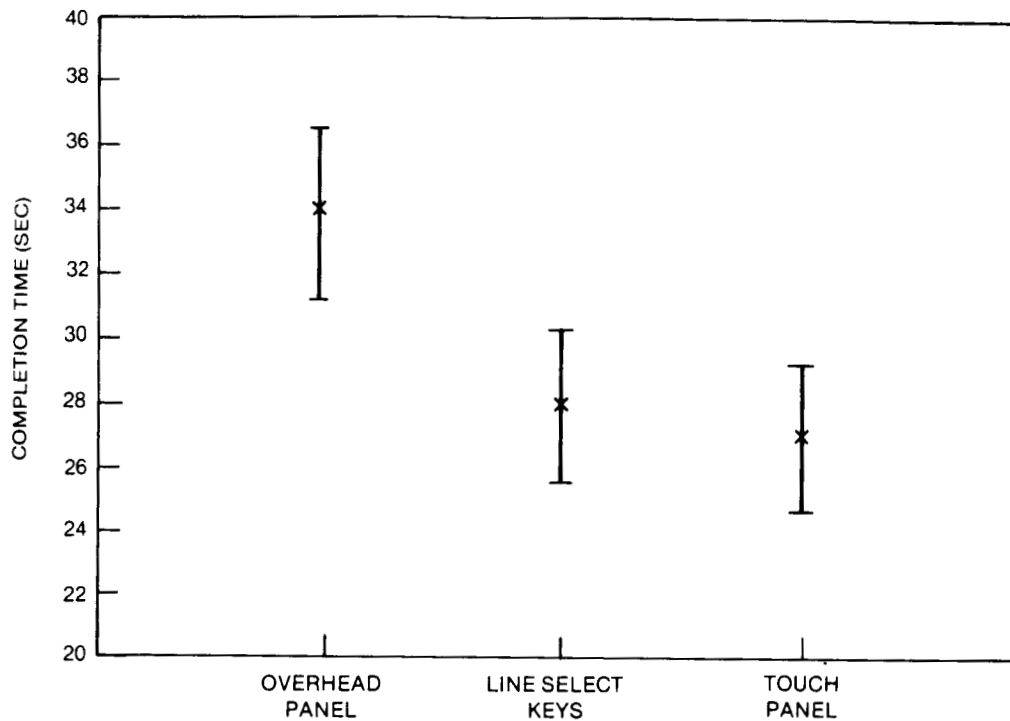
TABLE 3
SUMMARY OF PROCESSING TIME ANOVAs

VARIABLE	DEGREES OF FREEDOM	F RATIO	PROBABILITY
PRIMARY VARIABLES (IF P > 0.05 THE VARIABLE IS NOT LISTED)			
DISPLAY	1,11	21.15	0.001
CONTROLS	1,11	3.55	0.05
PROCEDURE	1,11	22.87	0.001
ALERT LEVEL			
ALERT	2,22	6.24	0.01
EVENT TYPE			
TYPE	8,88	10.04	0.001
ADVISORY EVENTS			
TYPE	4,44	14.54	0.001
CAUTION EVENTS			
TYPE	2,22	4.82	0.05



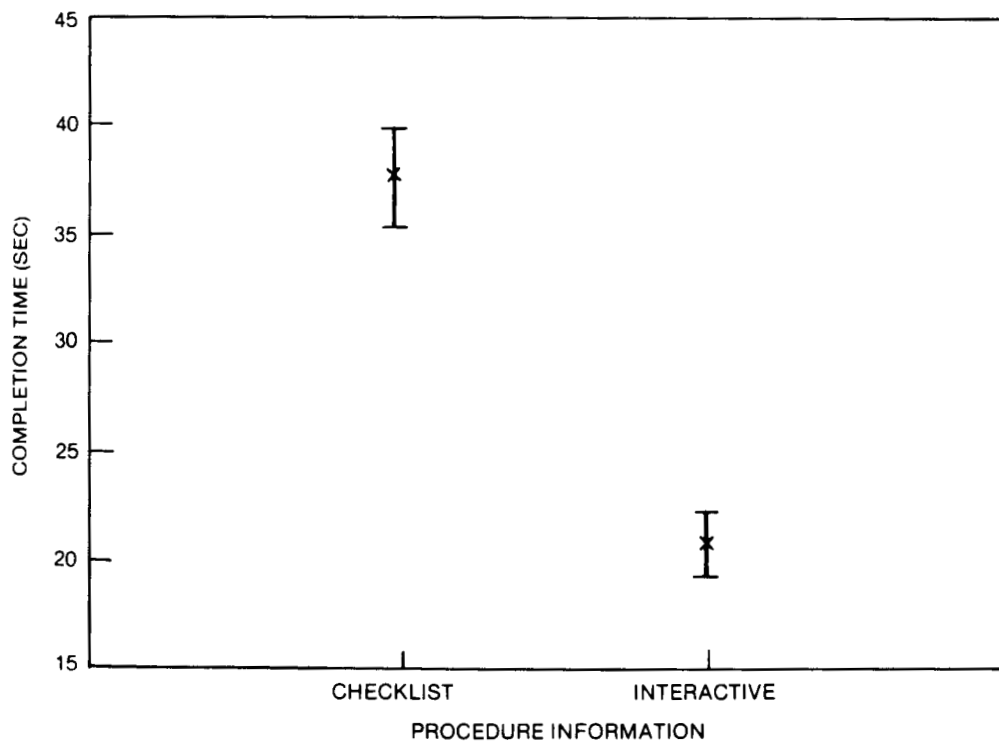
NOTE: BAR REPRESENTS ± 1 STANDARD ERROR OF THE MEAN

FIGURE 13. COMPLETION TIME AVERAGE ACROSS PILOTS FOR DISPLAY FORMATS.



NOTE: BAR REPRESENTS ± 1 STANDARD ERROR OF THE MEAN

FIGURE 14. COMPLETION TIME AVERAGE ACROSS PILOTS FOR DIFFERENT CONTROL INTERFACES.



NOTE: BAR REPRESENTS ± 1 STANDARD OF THE MEAN

FIGURE 15. COMPLETION TIME AVERAGE ACROSS PILOTS FOR TYPE OF PROCEDURE INFORMATION.

longer to process than pictorial formats. Figure 14 shows that the dedicated overhead panel takes 1.25 times longer to process than either the touch panel or the line select keys, and Figure 15 shows that paper checklists take 2 times longer to process than interactive procedures. Significant differences were obtained for the alert-levels, event-types, and event-types within an alert-level. Figure 16 shows the completion time by event-type.

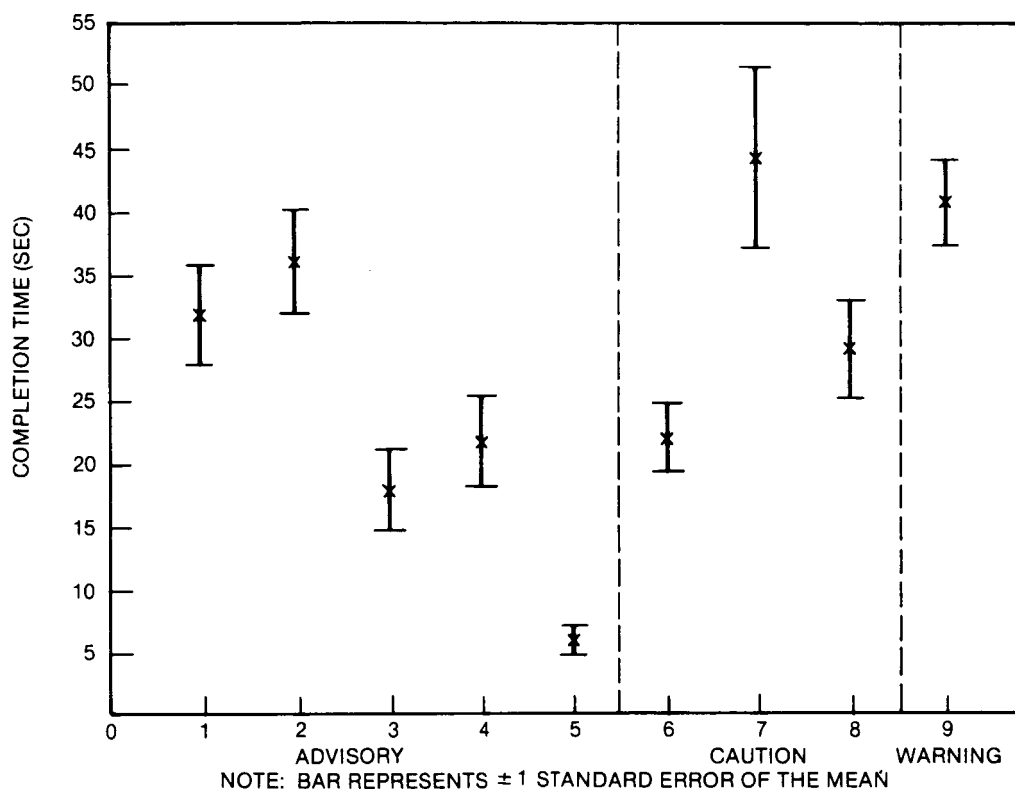


FIGURE 16. COMPLETION TIME AVERAGE ACROSS PILOTS FOR EVENT TYPE.

DISCRETE ACTIONS TO COMPLETE PROCEDURES

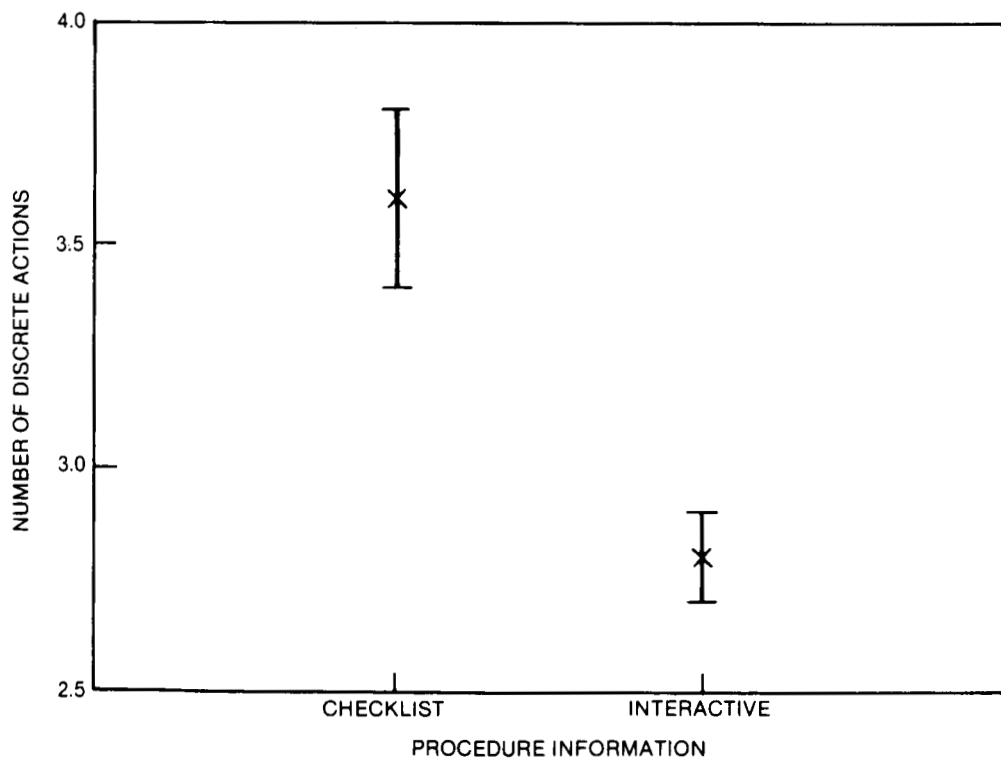
The results for the number of discrete actions are shown in Table 4. There were significant differences for procedure information and the trial-event interaction. The differences for procedure information are shown in Figure 17. The pilots required more actions to complete the procedures with the paper checklist than with the interactive procedures. There were significant differences for alert-level and for event-types within the alert-level. The number of processing steps by event-type is shown in Figure 18. These differences in event-type may account for the trial-event order interaction.

PROCEDURE ERRORS

The procedure errors were differentiated into four categories: (1) correct and according to procedure, (2) correct but not according to procedure, (3) correct but errors made in the procedures, and (4) incorrect or not completed. A Chi Square contingency analysis was performed on the frequency of occurrence of the various categories for the experimental conditions. The results of this analysis are shown in Table 5. The only variable that was significant was the type of procedure information. Table 6 presents the percentage of errors by procedure type. The interactive procedures showed a higher percentage of correct responses and more completions using the correct procedure than the paper checklists. A between-group analysis was performed to determine if the group who received the interactive procedure condition first had fewer errors with the paper checklists than the group who received the paper checklist condition first. The results are presented in Table 7. There were no significant differences between the two groups (Chi Square = 2.33 with 3 degrees of freedom).

TABLE 4
SUMMARY OF DISCRETE ACTIONS STEPS ANOVAs

VARIABLE	DEGREES OF FREEDOM	F RATIO	PROBABILITY
PRIMARY VARIABLES (IF P > 0.05 THE VARIABLE IS NOT LISTED)			
PROCEDURE	1,11	12.89	0.01
TE	1,11	6.94	0.05
ALERT LEVEL			
LEVEL	2,22	19.91	0.001
EVENT TYPE			
TYPE	8,88	14.82	0.001
ADVISORY EVENTS			
TYPE	4,44	17.90	0.001
CAUTION EVENTS			
TYPE	2,22	13.37	0.001



NOTE: BAR REPRESENTS ± 1 STANDARD ERROR OF THE MEAN

FIGURE 17. DISCRETE ACTIONS AVERAGE ACROSS PILOTS FOR TYPE OF PROCEDURE INFORMATION.

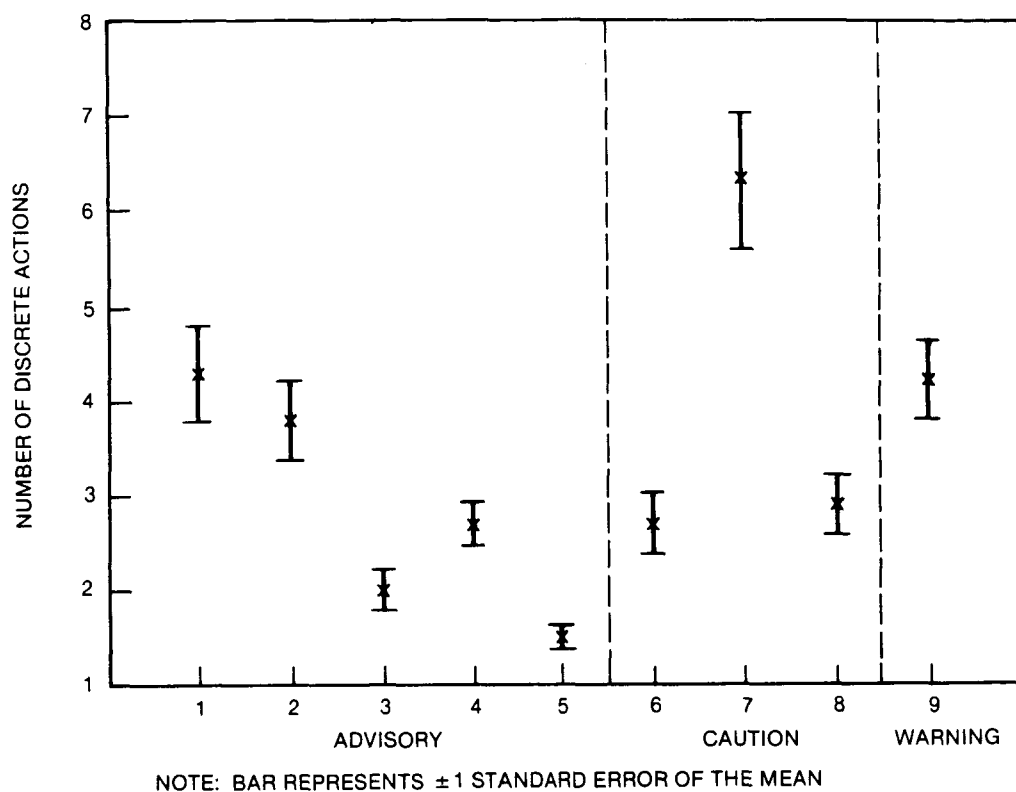


FIGURE 18. DISCRETE ACTIONS AVERAGE ACROSS PILOTS FOR EVENT TYPES.

TABLE 5
RESULTS OF THE CONTINGENCY ANALYSIS FOR PROCEDURE ERRORS

VARIABLE	CHI SQUARE	DF	PROBABILITY
DISPLAY	3.136	3	NS
CONTROL	7.446	6	NS
PROCEDURE	52.365	3	0.001

TABLE 6
PERCENTAGE OF PROCEDURE ERRORS FOR PROCEDURE TYPE

	PAPER CHECKLIST	INTERACTIVE PROCEDURE
CORRECT FOLLOWED PROCEDURE	38	66
CORRECT DID NOT FOLLOW PROCEDURE	16	7
CORRECT BUT ERRORS MADE	30	22
INCORRECT	16	5

TABLE 7
DIFFERENCES BETWEEN THE TWO GROUPS FOR PROCEDURE ERRORS
ON THE CHECKLIST CONDITION

	PAPER CHECKLIST FIRST	INTERACTIVE PROCEDURES FIRST
CORRECT FOLLOWED PROCEDURE	39.9	33.9
CORRECT DID NOT FOLLOW PROCEDURE	12.6	19.0
CORRECT BUT ERRORS MADE	30.1	29.8
INCORRECT	17.5	15.5

FLIGHT PERFORMANCE

A summary of the ANOVA tests for tracking performance are shown in Tables 8, 9, and 10. The display format variable was significant for the heading rms error analysis as well as a number of significant interactions. The text format showed less heading error than the pictorial format. On the other hand, the heading rms error for alert-level or event-type was not significant. There were no significant differences in the vertical speed error for the primary experimental variables. There were significant differences for alert-level and event-type as well as event-type within alert-level. The vertical speed error for the different alert types are shown in Figure 19. For the airspeed error, there were no main effects but two significant interactions. There were no differences for alert-level and event-type.

TABLE 8
SUMMARY OF VERTICAL SPEED RMS ERROR ANOVAs

VARIABLE	DEGREES OF FREEDOM	F RATIO	PROBABILITY
PRIMARY VARIABLES (IF $P > 0.05$ THE VARIABLE IS NOT LISTED)			
(NONE)			
ALERT LEVEL			
LEVEL	2,22	5.17	0.05
EVENT TYPE			
TYPE	8,88	3.53	0.01
ADVISORY EVENTS			
TYPE	4,44	17.90	0.001
CAUTION EVENTS			
TYPE	2,22	13.37	0.001

TABLE 9
SUMMARY OF HEADING RMS ERROR ANOVAs

VARIABLE	DEGREES OF FREEDOM	F RATIO	PROBABILITY
PRIMARY VARIABLES (IF P>0.05 THE VARIABLE IS NOT LISTED)			
DISPLAY	1,11	7.64	0.05
DT	1,11	6.09	0.05
CT	2,22	6.62	0.01
TE	1,11	5.42	0.05
PTE	1,11	6.26	0.05
DCPT	2,22	3.59	0.05
DCTE	2,22	4.73	0.05
ALERT LEVEL			
LEVEL	2,22	2.97	0.07
EVENT TYPE			
TYPE	8,88	1.16	0.33

TABLE 10
SUMMARY OF AIRSPEED RMS ERROR ANOVAs

VARIABLE	DEGREES OF FREEDOM	F RATIO	PROBABILITY
PRIMARY VARIABLES (IF P>0.05 THE VARIABLE IS NOT LISTED)			
DT	1,11	8.19	0.05
DCP	2,22	3.97	0.05
ALERT LEVEL			
LEVEL	2,22	1.28	0.30
EVENT TYPE			
TYPE	8,88	1.24	0.29

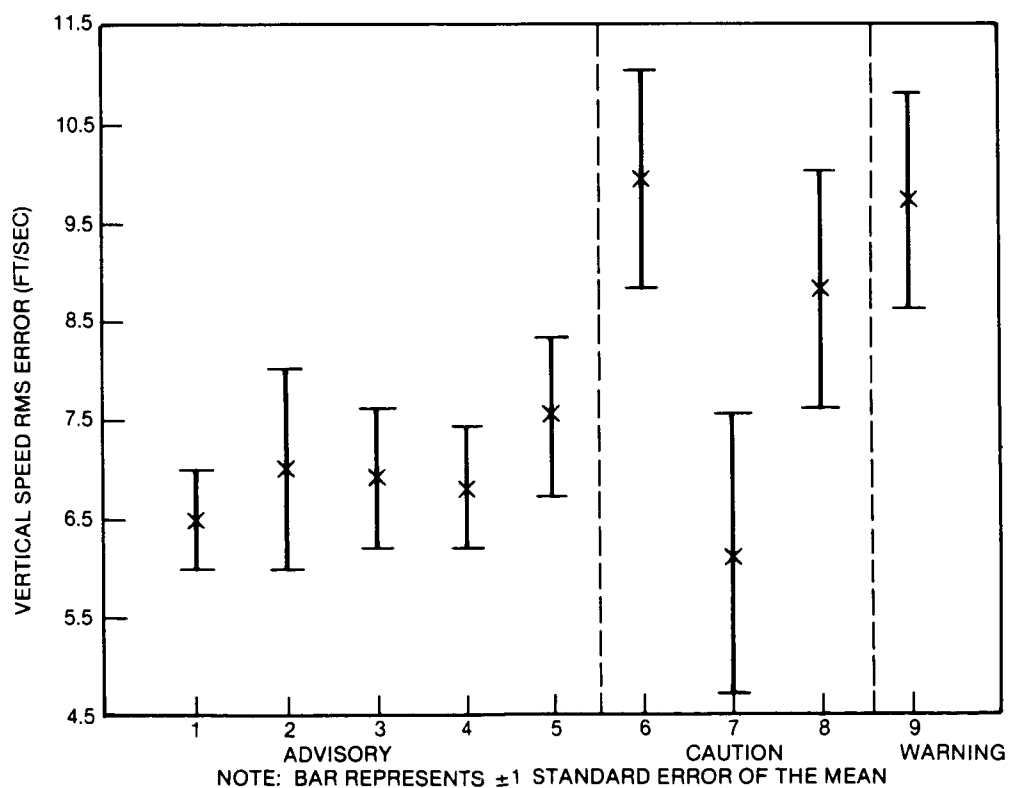


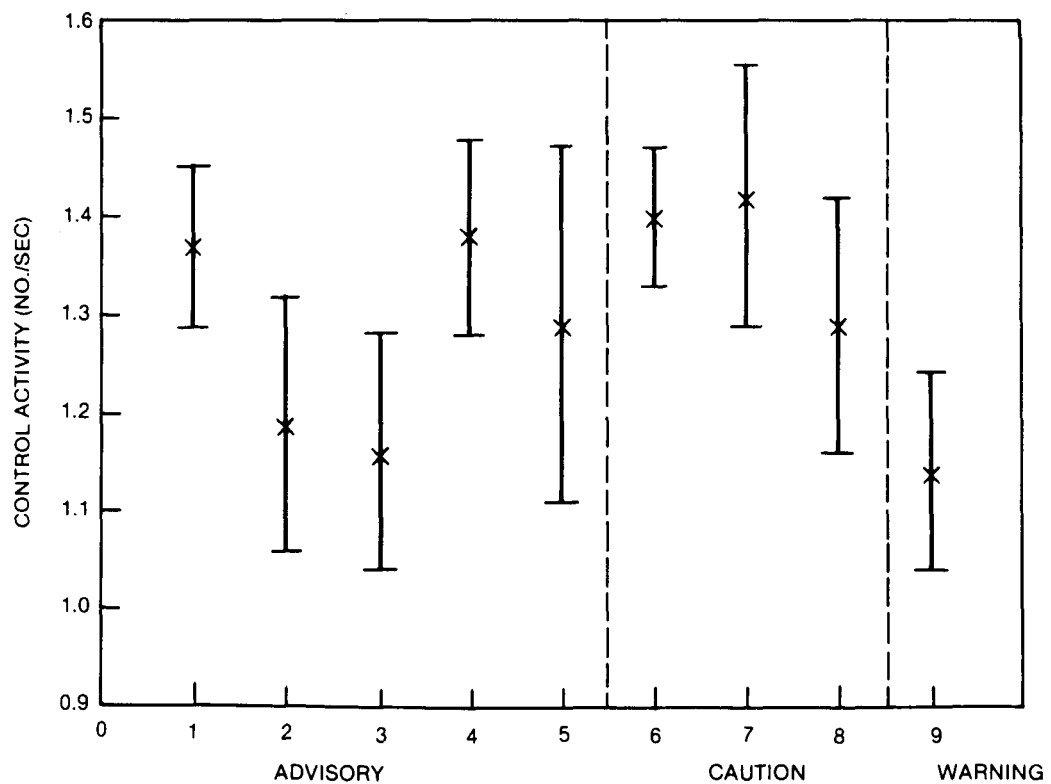
FIGURE 19. VERTICAL SPEED RMS ERROR AVERAGED ACROSS PILOTS FOR EVENT TYPES.

CONTROL ACTIVITY

The data in Table 11 show that event-order was significant. Event-type was not significant but alert-level was highly significant. Also event-types within an alert-level were not significant. The control activity for the different event-types is shown in Figure 20, which shows that the control activity was less for the warning alert which was only one event-type, while little difference occurred between the other event-types.

TABLE 11
SUMMARY OF CONTROL ACTIVITY ANOVAs

VARIABLE	DEGREES OF FREEDOM	F RATIO	PROBABILITY
PRIMARY VARIABLES (IF $P > 0.05$ THE VARIABLE IS NOT LISTED)			
EVENT	1,11	40.21	0.001
ALERT LEVEL			
LEVEL	2,22	16.78	0.001
EVENT TYPE			
TYPE	8,88	1.88	0.07



NOTE: BAR REPRESENTS ± 1 STANDARD ERROR OF THE MEAN

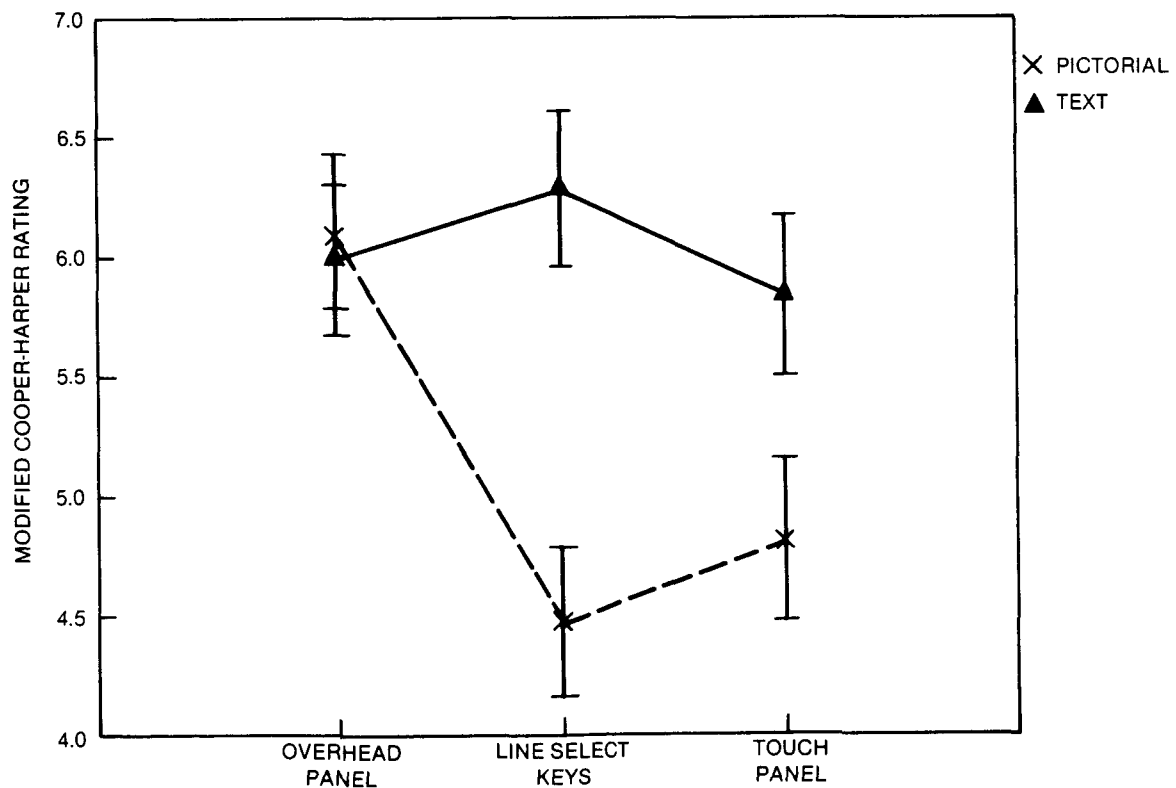
FIGURE 20. CONTROL ACTIVITY AVERAGED ACROSS PILOTS FOR EVENT TYPES.

PILOT RATING OF WORKLOAD

The workload ratings were analyzed with ANOVA, and the results are presented in Table 12. The pilots rated the display formats, the control interfaces, and the interaction of the two as significantly different. The average ratings for the display and control interfaces are shown in Figure 21. There were no differences between the two display formats for the dedicated overhead panel control interface, but the pictorial format was rated lower for the other two control interfaces. There were no significant differences between the two procedure conditions.

TABLE 12
SUMMARY OF WORKLOAD RATING ANOVAs

VARIABLE	DEGREES OF FREEDOM	F RATIO	PROBABILITY
PRIMARY VARIABLES (IF $P > 0.05$ THE VARIABLE IS NOT LISTED)			
DISPLAY	1,11	13.06	0.01
CONTROL	2,22	17.92	0.001
DC	2,22	7.02	0.01



NOTE: BAR REPRESENTS ± 1 STANDARD ERROR OF THE MEAN

FIGURE 21. WORKLOAD RATINGS AVERAGED ACROSS PILOTS FOR DISPLAY FORMATS AND CONTROL INTERFACES.

PILOT RESPONSES TO THE QUESTIONNAIRE

The pilots were asked to give their subjective preference for the treatment conditions as well as specific questions about the display formats, the controls, and the procedures. Table 13 shows the results of their preferences. It also shows that all the pilots preferred the pictorial formats and the interactive procedures and the majority preferred the touch panel.

The pilots responded to the other questions as follows:

1. Color is used to indicate the alert level of the faulted components; is this an appropriate use of color?

Color is satisfactory	80
Cyan is inappropriate as an advisory (usually indicates non-normal status)	10
Use color to differentiate partially failed control surfaces on the controls page.	10
2. Do you recommend any changes to the pictorial formats?

Format is satisfactory	60
Should be simpler	20
Should be more complex	20
3. With the overhead panel, is the system display necessary?

Yes, it is necessary	80
It is desirable	20
4. With automated system control, is system information necessary?

Yes, it is necessary	60
It is desirable	30
It is not required	10

**TABLE 13
PILOT PREFERENCES**

QUESTION	PREFERENCE	PERCENT
FORMAT	PICTORIAL	100
SYSTEM		
CONTROL	PICTORIAL	90
	ALPHANUMERIC TEXT	10
CONTROL INTERFACE	OVERHEAD PANEL	10
	TOUCH PANEL	60
	BEZEL PANEL	20
	TOUCH OR BEZEL	10
PROCEDURE	INTERACTIVE	100

DISCUSSION

DISPLAY FORMAT

Both the objective and subjective performance measures indicate that the pictorial formats are superior to the alphanumeric text for system status information. The pilots had problems with the alphanumeric text even though the systems were similar to those of the DC-10 and all except one of the pilots had experience on the DC-10. In general, the pilots had no problems with the pictorial schematics. Several pilots mentioned that it required more time to read the alphanumeric text and associate it with their knowledge of the system to determine the system status while the status was readily apparent with the pictorial schematic.

There are various questions involved with the development of pictorial formats for system information. One question is how far to go with pictorial information. Should a display format designer try to minimize text and use pictorial symbolics whenever possible, and when does the symbolic information start to become vague? Another question is the complexity of the displayed information. One of the guidelines for the design of the formats³ was to keep the information in a simple format. Although some pilots thought the formats were too simple, the majority of pilots thought that the complexity was satisfactory, and two pilots thought it should be less complex for easier assimilation.

The systems displays were presented in pages. The first page was a graphic display without quantitative information. If the pilot wanted quantitative information, he could call up the second page. Only one of the events required the pilot to look at the quantitative information which increased the number of steps for that event. However, it probably improved the response time for the other events. It appears that presenting information in pages going from a general status to more detailed information is a satisfactory approach.

Normally, when a dual hydraulic failure occurs, the pilots are required to change their flight plans and review the operability of the control surfaces. However, in this study the aircraft was on final approach and the pilot's options were to continue the approach or abort. The scenario did not force them to look at the control surface page in order to fly the aircraft and they only looked at it as part of the procedures. Therefore, this evaluation did not test the utility of a pictorial control surface page. One pilot commented that the text was as easy to comprehend as the pictorial. Another pilot said "at this point you don't need to look at the page, you just fly the aircraft." One pilot commented that there was too much information on the page. Another pilot wanted the degree of failure color-coded rather than the alert-level color-coded.

SYSTEM CONTROL

The performance measure, event processing time, and the pilot workload rating were sensitive to differences in the control interface. The touch panel and the bezel-mounted keys had the same event processing time and were rated equal in workload. The dedicated overhead panel had both a higher processing time and a higher workload. The results did not differentiate between type of control but to differences in the location of the control. Therefore, the critical factor, as far as the control interface, is the location and association with the system information. Since there were no differences between the number of processing steps or the error rate between the different controllers, it appears as if multifunction controls are not detrimental to performance.

The touch panel was preferred by the majority of the pilots. The principal reason was that the location of control is the same as the location of the information. With the bezel-mounted switches, mental effort was required to associate the switch location with the information location.

Pilot comments on switch activation were that the touch panel causes more problems than either the overhead or bezel-mounted switches. This was primarily due to the parallax problem with the virtual switch location, switch bounce, and the sensitivity of the touch screen. This led to turning the wrong component on, turning the component on-off in rapid succession, and repeated touching of the screen.

PROCEDURE INFORMATION

As anticipated, interactive procedures improved performance over a paper checklist. This was evident by the decrease in detection time, processing time, processing steps, and error rate. Although the interaction of procedure information and the alert level could not be analyzed, it appears that the decrease in detection time was caused by a decrease in time for the advisory alerts. The pilots could easily miss an advisory since there was no master annunciation and the aural tone occurred once. The only remaining cues were the message on the alert display and the magenta procedures on the SSD (if it was on the correct status page). These procedures would act as an additional cue to the pilot, and he would respond to the status display in addition to the alerting system.

The paper checklist required more processing time due to finding the checklist, looking up the procedure, and reading it off the checklist. Also, the information was displayed in two different formats with the interactive procedures. With the pictorial display, the action adverb with an arrow to the component was displayed, and with the text the component name was followed by the action. The latter required the pilot to relate the name associated with the status information. Even though there was not a significant interaction between display format and procedure information, the pictorial display with the interactive procedure had 57 percent of the event processing time compared to the alphanumeric text with the interactive procedures. With the paper checklist, the pictorial had 87 percent of the processing time compared to the text. This implies that reducing the procedure information to pictorial information with minimum text reduces the number of mental steps and improves performance.

Another improvement with interactive procedures is in the error rate. This is due to (1) the display of the correct procedure instead of the crew relying on their memory or looking it up in the paper checklist, and (2) information feedback by the removal of the procedure once it has been completed. These factors reduce both the number of processing steps and the error rate.

The most significant problem with interactive procedures was revealed by an observation by the experimenter. The pilots responded to the procedures without diagnosing the problem. In fact, it turned out to be a game of trying to remove the procedure information from the display without ascertaining the status of the system. This would cause a problem if the interactive procedures do not cure the problem or provide assistance. The same problem will exist with automated systems when the pilot has to provide manual backup. Will the pilots have enough knowledge about the system operation to be able to respond correctly and in a timely manner?

FLIGHT PERFORMANCE

The flight performance was analyzed to determine if the experimental variables had an effect upon the primary flight task. There does not appear to be consistent results between the experimental variables and the flight performance measures. The text format shows less heading rms error, but there were a number of significant interactions. A possible explanation of tracking scores is that the sampling window for the rms deviations was too small to obtain reliable scores.

The only consistent difference in flight performance was in the vertical speed rms error where the caution and warning event types had consistently higher error scores than the advisories. In addition, the control activity, a measure of attention paid to the primary flight task, was less with the warning event type. These effects may be due to the type of failure rather than the alert-level since the hydraulic caution and warning alerts affect the controllability of the aircraft.

The pilot's primary task was to fly the aircraft in a high workload situation. The pilots continued to fly the aircraft within reasonable limits and kept it on the approach pattern on every trial. Therefore, if the pilots exceeded their workload capacity, it appeared as degradation in processing the alert events rather than the primary flight task.

ALERTING SYSTEM

The performance measures were analyzed according to alert level to determine if the results concurred with the alerting systems standardization study.¹⁹ However, due to the noncentral location of the alert display and the emphasis of the study, the pilots tended to look at the SSD display prior to looking at the alert display. The advisory alerts had significantly longer detection times than the other two alerts. Advisory alerts only have a single tone and the text message on the alert display. Due to the high workload and the frequency of occurrence of the alerts, the advisory alerts were often missed or the pilots delayed acknowledgment. Another factor that contributed to the longer detection times was the difference in scoring. The caution and warnings were scored from the time the event occurred to the cancellation of the MCW. Advisories were scored from the time the event occurred to the paging of the SSD.

The only other effect of alert-level appeared to be the control activity where the warning alert had less activity than either the advisories or the cautions. This would indicate that the pilots were paying more attention to the alerts than the primary flight task. However, this may be due to the nature of the warning alert since they were all dual hydraulic failures which affected the controllability of the aircraft.

Another observation by the experimenter was that the majority of pilots read down the list and expected the last alert to occur at the bottom of an alert category instead of at the top of the category. It appears to be natural for a person to read down a video display terminal and have the latest occurring line appear at the bottom of the screen. Although the pilots could learn that the last alert is at the top, they may regress, especially if there are other computer readouts with the latest information at the bottom of the list.

RECOMMENDATIONS

As a result of this study, the following recommendations are made for future research on aircraft system displays and application for future cockpit design.

1. Pictorial formats should be used to display aircraft systems information whenever possible. The addition of text to these displays should be kept to a minimum. Further studies are required to determine how complex this information should be.
2. Even though graphic design principles^{20, 21} were used to develop the formats for this study³, there is a lack of empirical evidence that these principles are better than any other principles for system display design. Further studies are required on design principles for system display guidelines and validation by empirical evaluation.
3. System controls should be located and associated with the display of system information. The closer these controls are to the pilot's primary flight task, the better the performance. If the technical problems can be solved with the touch panels; (i.e., parallax, virtual switch size, feedback, etc.), they are an acceptable method of control, since the control location is coincident with the status information.
4. With automated aircraft systems, the crew should have knowledge of the system and be able to provide manual backup. This requires the crew to have access to system status and the backup procedures. Interactive procedures improve the crew's ability to process the events but they become dependent upon this interactive information instead of learning the system. More work is required to determine how these procedures should be used and how to keep the crew involved in the task.
5. Since this study found that the pilot read the bottom alert on the alert display as being the latest alert, the guidelines on the chronological listing of alerts from top-down that were developed as part of the Alerting Systems Standardization Study¹ should be reviewed.

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APPENDIX A

DESCRIPTION OF FUEL AND HYDRAULIC SYSTEMS

FUEL SYSTEM

The fuel model provides positive fuel pressure for feeding both engines. The consumption of fuel depends upon the throttle setting of the engines. Also, the engines could be set so that one would burn more fuel than the other to create a fuel imbalance. The fuel system consisted of three tanks: two main wing tanks and an auxiliary fuselage tank. Each tank had two fuel pumps where each pump had adequate flow for supplying both engines during takeoff. The fuel manifold interconnects the three tanks with fill valves, and crossfeed valves supply the engine manifolds. Each main tank has a float valve switch which will continually fill the main tank from the auxiliary tank as long as an auxiliary tank pump is on. The auxiliary tank pumps will turn off automatically when the tank is empty. The fuel system schematic is shown in Figure A-1.

The normal configuration is to have the aft pumps on in the main tanks, a pump on in the auxiliary tank, the main tank fill valves armed, and the crossfeed valves closed. If a fuel imbalance occurs, a fuel schedule advisory occurs. If fuel is remaining in the main tank, the fill valve on the high tank is closed until the two tanks are balanced. If no fuel is remaining in the auxiliary tank, then the fill valve is closed and the crossfeed valve is open until the tanks are balanced. If there is low pressure in the engine manifold, a caution alert occurs. The forward pump is turned on and if the low pressure remains, the crossfeed valves are opened to supply fuel from either the auxiliary tank or the other main tank.

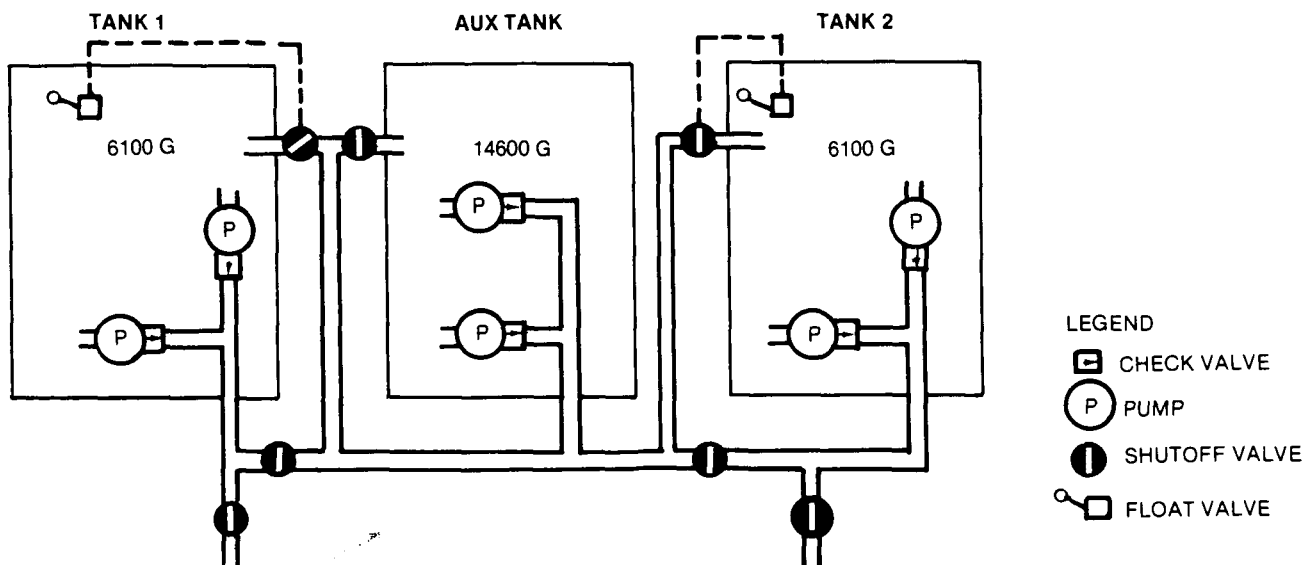


FIGURE A-1. SCHEMATIC OF THE FUEL SYSTEM

HYDRAULIC SYSTEM

The hydraulic system consists of three parallel continuously pressurized systems as shown in Figure A-2. Independent reservoirs supply fluid to each system. System 1 is powered by a left-engine-driven pump and a auxiliary pump for backup and ground operations. System 2 is normally powered by a right-engine-driven pump but with loss of pressure the left-engine pump is automatically turned on if armed. System 3 is powered by a right-engine-driven pump, an auxiliary pump for backup and ground operations, and a ram air turbine. In addition, there is a reversible motor pump which transfers power between Systems 1 and 2, if there is loss of pressure in either system.

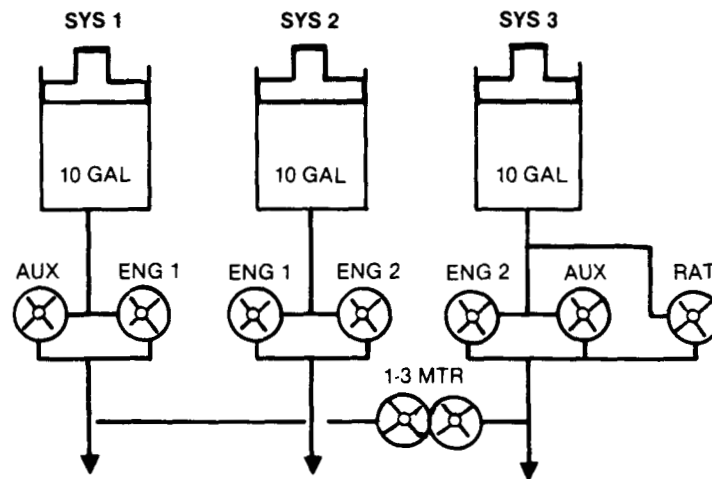


FIGURE A-2. SCHEMATIC OF THE HYDRAULIC SYSTEM

The relationship between the hydraulic system and the control surfaces is shown in Figure A-3. The loss of one hydraulic system will result in a reduction in the number of active spoilers, the possibility of the loss of a horizontal stabilizer actuator reducing the pitch trim rate, and the loss of an actuator to the flaps/slats resulting in a reduction in the airspeed at which they will deploy. The loss of two hydraulic systems will reduce the redundancy of the primary control surfaces affecting the control power, reduce the number of active spoilers, the loss of either the flaps or slats, and depending on which hydraulic system is lost, the loss of pitch trim.

If there is low pump pressure, it will cause an advisory alert without the loss of system pressure. Crew actions are to clean up the system; that is, to turn on the auxiliary pump and turn off the affected engine-driven pump. With the loss of hydraulic system pressure, a caution alert occurs and action by the crew is to clean up the hydraulic system and to determine the effect on flight operation. With the loss of a second hydraulic system, a warning alert occurs. The action by the crew is to clean up the affected hydraulic system and to determine the effect upon the aircraft.

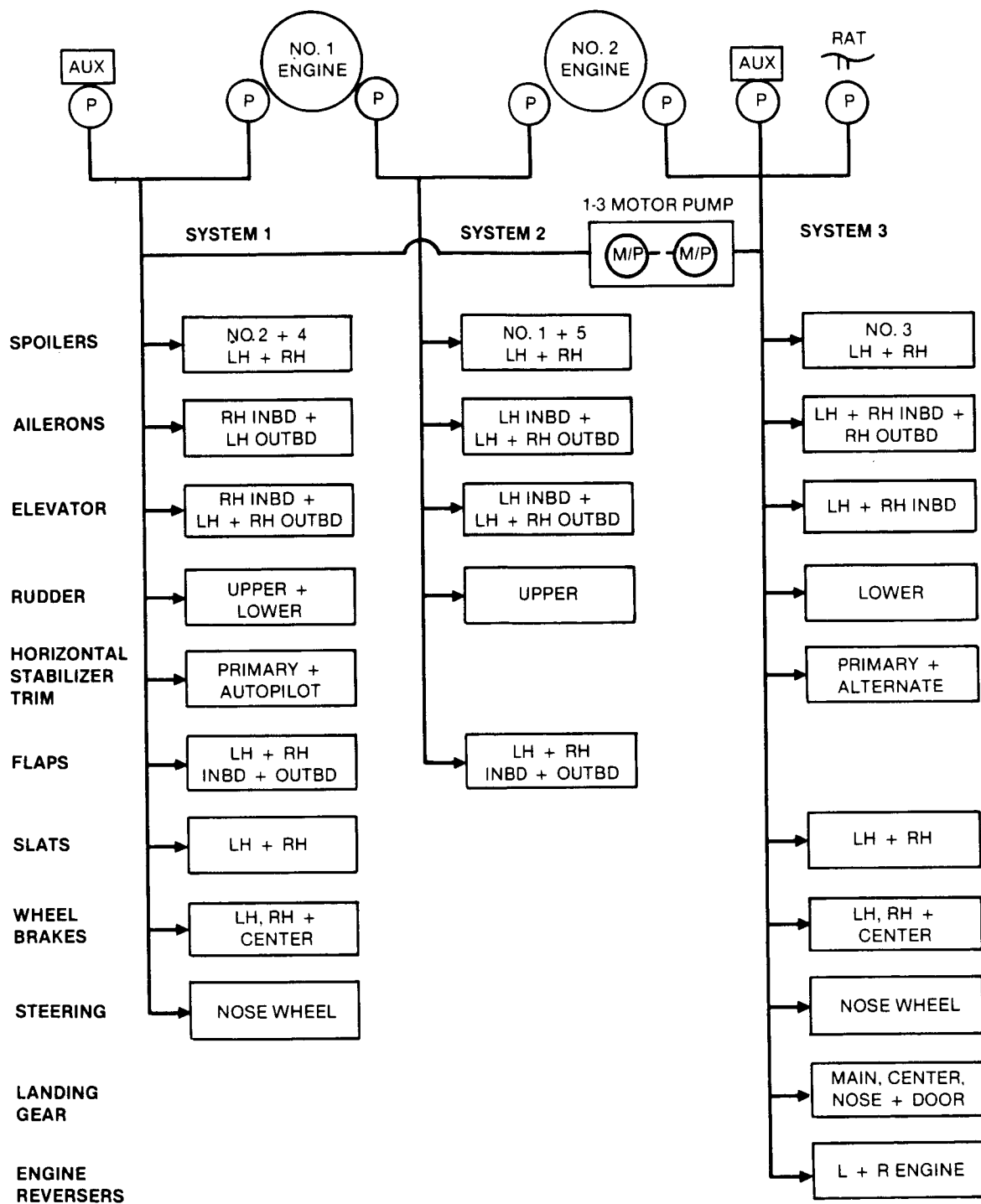


FIGURE A-3. HYDRAULIC SYSTEM BLOCK DIAGRAM

APPENDIX B SYSTEM STATUS DISPLAY FORMATS

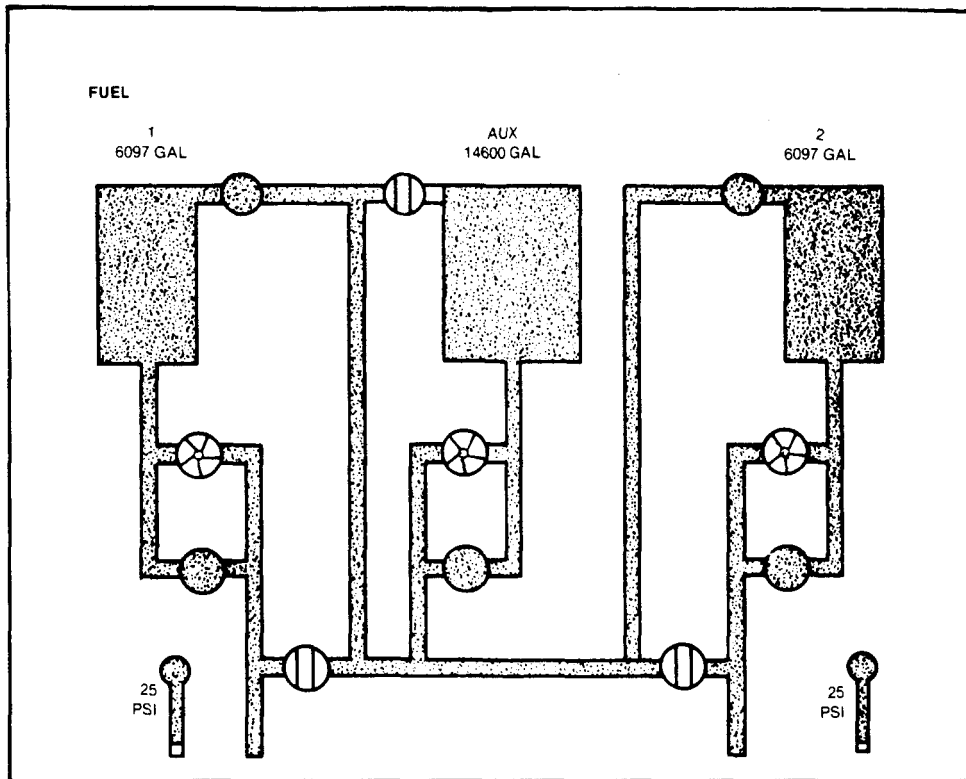


FIGURE B-1. PICTORIAL FORMAT FOR THE FUEL SYSTEM

FUEL		
TANK 1	AUX TANK	TANK 2
6097 GA	14600 GA	6097 GA
FILL VLV	FILL VLV	FILL VLV
AUTO	CLOSED	AUTO
FWD PUMP	FWD PUMP	FWD PUMP
OFF	OFF	OFF
AFT PUMP	AFT PUMP	AFT PUMP
ON	ON	ON
XFEED VLV		XFEED VLV
CLOSED		CLOSED
PRESSURE		PRESSURE
25 PSI		25 PSI

FIGURE B-2. ALPHANUMERIC TEXT FORMAT FOR THE FUEL SYSTEM

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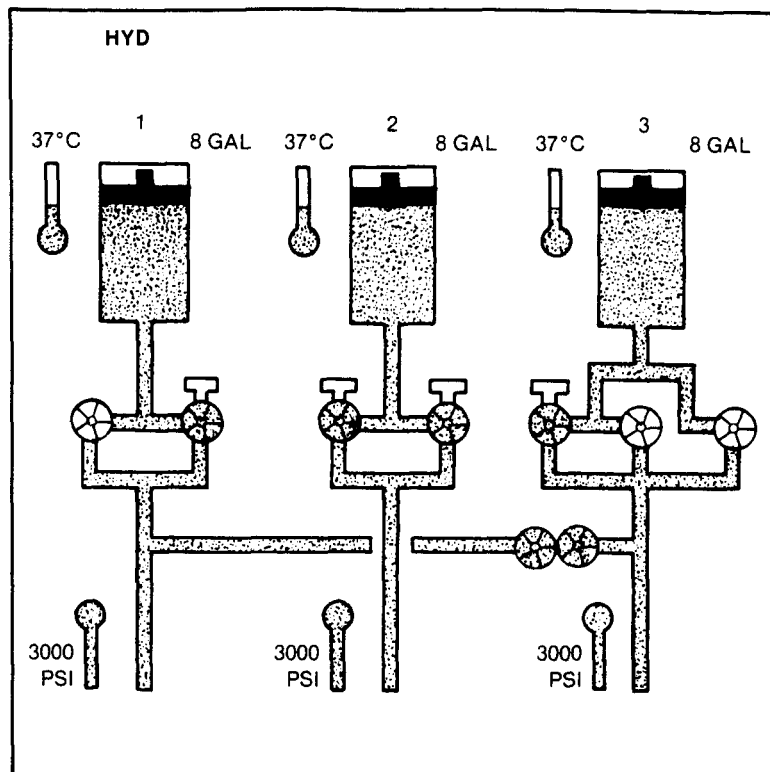


FIGURE B-3. PICTORIAL FORMAT FOR THE HYDRAULIC SYSTEM

HYD		
QUANTITY	QUANTITY	QUANTITY
8 GA	8 GA	8 GA
TEMP	TEMP	TEMP
37 C	37 C	37 C
PRESSURE	PRESSURE	PRESSURE
3000 PSI	3000 PSI	3000 PSI
E1 PUMP	E1 PUMP	E2 PUMP
ON	ARMED	ON
AUX PUMP	E2 PUMP	AUX PUMP
OFF	ON	OFF
	MTR PUMP	RAT
	ARMED	OFF

FIGURE B-4. ALPHANUMERIC TEXT FORMAT FOR THE HYDRAULIC SYSTEM

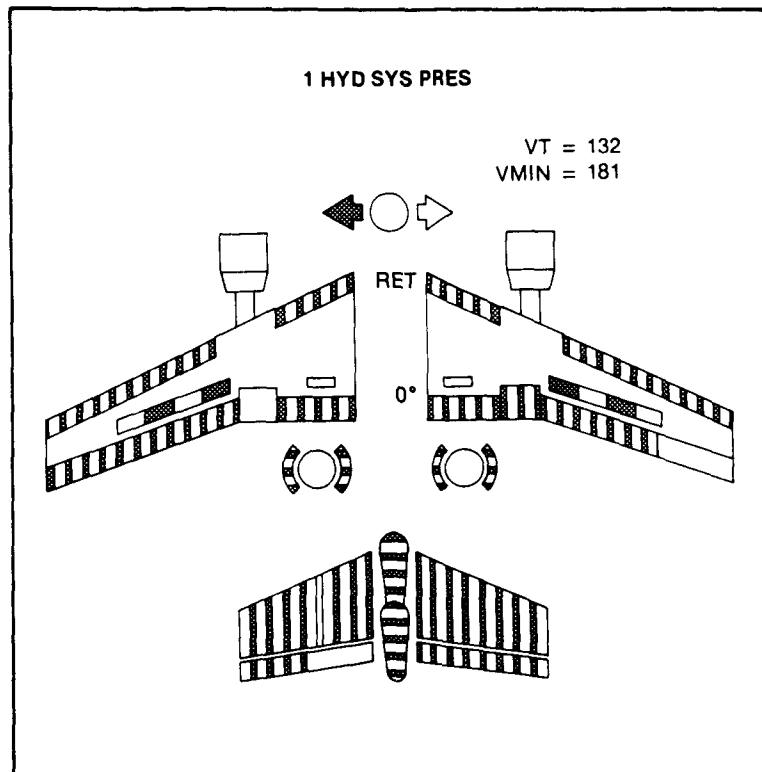


FIGURE B-5. PICTORIAL FORMAT FOR THE CONTROL SURFACES

1 HYD SYS PRES

VT = 132
VMIN = 181

ELEVATORS	RATE REDUCED	
AILERONS	RATE REDUCED	
RUDDER	RATE REDUCED	
LONG TRIM	RATE REDUCED	
SLATS	MAY NOT EXTEND	RET
FLAPS	MAY NOT EXTEND	0°
SPOILERS	EFFECT REDUCED	
BRAKES	1 INOP	
REVERSERS	NORMAL	
NSE GR STEER	L INOP	
LDG GEAR	NORMAL	

FIGURE B-6. ALPHANUMERIC TEXT FORMAT FOR THE CONTROL SURFACES

APPENDIX C PAPER CHECKLIST

1-2 HYD SYSTEM PRESS (W)	2-3 HYD SYSTEM PRESSURE (W)	1-3 HYD SYSTEM PRESSURE (W)
3 AUX PUMP 1-2 ENG PUMPS MOTOR PUMP CONTROLLABILITY FOR 0/RET AND 0/EXT, APP & LDG PROCED NEAREST AIRPORT APPROACH IF 0/RET, FLAPS/SLATS AIRSPEED IF SLATS NOT EXTENDED, 0/RET LDG OTHERWISE, 35/RET LDG	1 AUX PUMP 2-3 ENG PUMPS MTR PUMP CONTROLLABILITY APP & LDG PROCED NEAREST AIRPORT APPROACH IF SLATS RETRACTED, FLAPS/SLATS IF SLATS DO NOT MOVE, FLAPS/SLATS AIRSPEED IF FLAPS/SLATS DO NOT MOVE, 0/RET LDG IF SLATS DO NOT MOVE, FLAPS/SLATS 22/RET LDG OTHERWISE, FLAPS/SLATS IF SLATS RETRACT, FLAPS/SLATS 22/EXT LDG OTHERWISE, 35/EXT LDG	2 ENG 2 PUMP 1-3 ENG PUMPS MTR PUMP CONTROLLABILITY FOR 35/RET OR 22/RET, APP & LDG PROCED NEAREST AIRPORT APPROACH AIRSPEED FLAPS/SLATS IF FLAPS POSITION DISAGREES, 0/RET LDG OTHERWISE, 35/RET LDG
ON OFF OFF REVIEW REVIEW SELECT REVIEW SELECT 0/EXT REDUCE PERFORM PERFORM PERFORM	ON OFF OFF REVIEW REVIEW SELECT APPROACH 0/EXT 15/EXT REDUCE PERFORM 22/EXT PERFORM 35/EXT 22/EXT PERFORM PERFORM	ON OFF OFF REVIEW REVIEW SELECT REVIEW SELECT REDUCE 35/RET PERFORM PERFORM

FUEL SYSTEM PRESSURE LOW (C)

FORWARD PUMP ON

IF PRESSURE REMAINS LOW,

1 & 2 XFEED OPEN

1 & 2 XFER CLOSE

FUEL QUANTITY MONITOR

FUEL CONFIGURATION (A)

IF FUEL IN AUXILIARY TANK,

AUXILIARY PUMP ON

LO TK XFER VALVE OPEN

HITK XFER VALVE CLOSE

WHEN BALANCED,

HITK XFER VALVE OPEN

NO FUEL IN AUXILIARY TANK

HITK FWD PUMP ON

HITK XFER VALVE CLOSE

HITK XFEED OPEN

WHEN BALANCED,

HITK XFEED CLOSE

HITK FWD PUMP OFF

1 HYD SYSTEM PRESSURE (C)

ENG PUMP OFF

AUX PUMP OFF

MTR PUMP OFF

CONTROLLABILITY REVIEW

APPROACH

FLAPS/SLATS EXTEND

IF FLAPS/SLATS DO NOT MOVE,

AIRSPEED REDUCE

FLAPS/SLATS 15/EXT

IF FLAPS/SLATS DO NOT MOVE,

0/RET LDG PERFORM

IF ONLY FLAPS MOVE,

FLAPS/SLATS 22/EXT

22/RET LDG PERFORM

OTHERWISE,

FLAPS/SLATS 35/EXT

IF SLATS RETRACT,

FLAPS/SLATS 22/EXT

22/EXT LDG PERFORM

OTHERWISE,

35/EXT LDG PERFORM

2 HYD SYSTEM PRESSURE (C)

ENG PUMPS OFF

CONTROLLABILITY REVIEW

APPROACH

FLAPS/SLATS EXTEND

IF FLAPS DO NOT MOVE,

0/EXT LDG PERFORM

3 HYD SYSTEM PRESSURE (C)

IF QUANTITY IS OK,

RAM AIR TURBINE UNLOCK

OTHERWISE,

ENG PUMP OFF

AUX PUMP OFF

MTR PUMP OFF

CONTROLLABILITY REVIEW

APPROACH

FLAPS/SLATS EXTEND

IF FLAPS/SLATS DO NOT MOVE,

AIRSPEED REDUCE

FLAPS/SLATS 15/EXT

IF FLAPS/SLATS DO NOT MOVE,

0/RET LDG PERFORM

IF ONLY FLAPS MOVE,

FLAPS/SLATS 22/EXT

22/RET LDG PERFORM

OTHERWISE,

FLAPS/SLATS 35/EXT

IF SLATS RETRACT,

FLAPS/SLATS 22/EXT

22/EXT LDG PERFORM

OTHERWISE,

35/EXT LDG PERFORM

APPENDIX D PILOT BRIEFING

The objective of this study is to evaluate alternative display control interfaces for aircraft systems control. Control of aircraft systems on advanced commercial aircraft will be automated. The issues are how the crew will interact with these automated systems and their ability to operate the systems in a manual backup mode. The specific issues addressed are:

1. How should the system information be displayed on multifunction displays?
2. If multifunction controls are used, do they degrade performance as compared to dedicated controls?
3. For manual system control, do interactive procedures on the display improve performance compared to paper checklists?

The study will attempt to evaluate your ability to interact in both normal and abnormal situations with the fuel and hydraulic systems while flying an approach. The aircraft is a two-engine widebody with handling qualities of a DC-10. Normally, this is a two-crew operation where one pilot flies the aircraft and the other interacts with the system. However, we are assuming a worst-case condition where one of the pilots is incapacitated.

The flight displays are electromechanical instruments. The left center CRT is the System Status Display and the right display is a dedicated alert display. The other portion of the right display would normally be occupied by engine displays. It is assumed that these displays are interchangeable and for normal two-crew operations they would be reversed. The displays have been moved aft so that they are within reach to touch the controls. However, this does create a viewing angle and parallax problem.

The SSD display has multiple pages which contain the following information:

1. Phase of flight information — These are text displays that contain information pertinent to the phase of flight.
2. Hydraulic system — There are two pages: one consists of the status and the other includes quantitative information with the status.
3. Fuel system — There are two pages similar to the hydraulic system.
4. Control surface — This contains information on the operability of the control surface as well as position information.

You may select any page at any time by using the control panel which is located in the pedestal forward of the throttle quadrant. Normally, the flight phase page will be displayed except when there is either a caution or warning alert. When the latter cases occur, the appropriate systems page is displayed. The selection of the pages will depend on the phase of flight, an alert, or manual selection via the control panel. Part of the evaluation will have procedures on the pages that will interact with system state and actions performed by the pilot.

You will be given two different display formats as an experimental condition: one will be pictorial schematics of the systems and a pictorial of the control surfaces and the other will be text containing the same information. Another experimental condition will be procedures on the system display that interact with the system state and the actions performed by the pilot. The other condition will be without these procedures and you will have to rely on paper checklists.

The schematics are self-explanatory. The text is structured so that the spatial relationships of components are the same as on the schematics. The first page of the system shows the status of the components and the second page adds quantitative information to the status. The control surface page shows a plan view of the aircraft with an outline of the control surfaces. If a control surface is operating normally, it is shown by a green outline. If it is inoperative, it is shown with solid fill in the appropriate alert-level color. If it is partially operative (i.e., with one actuator), it is shown with partial fill in the appropriate alert-level color.

The color code is the following:

1. The alert-level colors are red — warning, amber — caution, and cyan — advisory.
2. White is used for titles and names of the systems and the components.
3. Green is used for systems and components that are operating normally.
4. Magenta is used for the procedures.

For the experimental condition where there are procedures on the system pages, the schematics will have the action and an arrow to the component when there is a non-normal condition. For the text and the displayed procedures that are not interactive, the component or system and the action are identified. For the interactive procedures they will disappear after the action is performed. The noninteractive procedures will remain displayed until the non-normal condition goes away.

You will be able to interact with the fuel and hydraulic systems by one of three methods, depending upon the experimental condition: (1) a dedicated overhead panel, (2) a touch panel overlay of the SSD, and (3) bezel-mounted switches where dashed lines show which switch a component is connected, similar to line select keys. These inputs will allow you to control the state of the system.

The fuel system consists of two main tanks and an auxiliary tank. Each tank has two pumps and a fill valve. There is a manifold between the tank with two crossfeed valves that permit total crossfeed capability and transfer between the tanks. The main tank fill valves have float switches which close automatically when the tanks are full. The auxiliary tank pumps will also turn off automatically when the tank is empty.

The hydraulic system consists of three parallel systems. System 1 is powered by a left-engine-driven pump and an auxiliary pump. System 2 is normally powered by a right-engine pump but with loss of pressure the left-engine pump turns on if it is armed. System 3 is powered by a right-engine pump, an auxiliary pump and a ram air turbine. In addition, a reversible motor pump transfers power between Systems 1 and 3 when there is a loss of pressure in either system.

The hydraulic system is interconnected with the control surfaces similar to the DC-10. So with the loss of a hydraulic system, the controllability of the aircraft is affected.

The alert system will consist of the MCW display on the glareshield, aural tones, and the alert list on the right display. The alert list will contain text annunciations of the alerts in their appropriate color. There are three distinct aural tones for caution, warning, and advisory alerts. Pushing the MCW cancels the light and the aural, but the alert list remains until the alerting condition goes away.

First, you will go through the normal start procedures. Second, you will go through the approach with a sample of alerts, and this will be repeated with each of control interfaces and the displays. You will have the chance to try more flights if you think it is necessary.

You will be flying with manual throttles and a flight director. The handling qualities are that of a DC-10. You will start at a heading of 360 and a speed of 220 knots. The course pointer is aligned with the ILS. You will be given vectors to the ILS and approximately 10 seconds after these are given, the flight director and fast/slow indicator will present these commands as if you rotated the speed and heading select controls.

Since we are attempting to measure workload with the different configurations, perform all the necessary normal and abnormal functions during the approach. The primary emphasis in this evaluation is the accuracy and the speed at which you can interact with the systems. Continue in the approach until you think it is unsafe to land and then initiate a go-around maneuver. Normally, the simulation will be terminated after you intercept the glideslope.

**APPENDIX E
EVALUATION FORM**

NO: _____

DATE: _____

NAME: _____ POSITION: _____

BIRTHDATE: _____

WEAR GLASSES/CONTACTS FOR FLYING? YES ____ NO ____

ACTIVE FLIGHT DUTY? YES ____ NO ____

TRANSPORT EXPERIENCE:

AIRCRAFT TYPE/MODEL	POSITION	NO. OF HRS	DATE	RATED
---------------------	----------	------------	------	-------

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CONDITION

RATING

1	
2	
3	
4	
5	
6	
7	
8	
9	
10	
11	
12	

1) Which of the two formats, pictorial schematics or text, do you prefer for the following systems information? (Please explain)

a) Fuel and hydraulic systems.

b) Flight control surfaces.

2) In both formats color is used to indicate the faulted components and the alert level. Is this the appropriate use of color?
Do you have any recommendations for other uses in this application?

3) Do you have any suggestions for changes in the pictorial formats?

4) Do you have any suggestions for changes in the text formats?

5) Which of the control interfaces do you prefer: dedicated overhead panel, touch panel or the bezel panel? (Please explain)

6) With the dedicated control panel is the system information necessary? (Please explain)

7) With automated control of the systems is the system information necessary? (Please explain)

8) Which do you prefer: the interactive procedures or the paper checklists? (Please explain)

APPENDIX F **ANALYSIS OF VARIANCE TABLES**

Acknowledgment Time

Primary Variables

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN ERROR	44325.58314 8542.27778	1 11	44325.58314 776.57071	57.08	0.0000
2	DIS ERROR	22.67109 3852.19164	1 11	22.67109 350.19924	0.06	0.8039
3	CON ERROR	605.61820 10909.49855	2 22	302.80910 495.88630	0.61	0.5520
4	DC ERROR	2626.45294 17137.75017	2 22	1313.22647 778.98864	1.69	0.2084
5	PRO ERROR	2478.15624 2095.98317	1 11	2478.15624 190.54392	13.01	0.0041
6	DP ERROR	99.38593 7739.47711	1 11	99.38593 703.58883	0.14	0.7142
7	CP ERROR	957.17156 11152.08233	2 22	478.58578 506.91283	0.94	0.4042
8	DCP ERROR	127.08676 10558.38906	2 22	63.54338 479.92678	0.13	0.8767
9	REP ERROR	6386.86014 5861.25873	1 11	6386.86014 532.84170	11.99	0.0053
10	DR ERROR	352.33165 3346.09297	1 11	352.33165 304.19027	1.16	0.3049
11	CR ERROR	1685.67251 11014.58635	2 22	842.83626 500.66302	1.68	0.2088
12	DCR ERROR	1348.63738 15262.91523	2 22	674.31869 693.76887	0.97	0.3940
13	PR ERROR	2367.04959 4885.46350	1 11	2367.04959 444.13305	5.33	0.0414
14	DPR ERROR	14.18527 5461.15098	1 11	14.18527 496.46827	0.03	0.8688
15	CPR ERROR	832.80051 11083.68990	2 22	416.40026 503.80409	0.83	0.4507

16	DCPR ERROR	77,37120 11472,99456	2 22	38,68560 521,49975	0.07	0.9287
17	EVE ERROR	5327,92951 2990,68082	1 11	5327,92951 271,88007	19.60	0.0010
18	DE ERROR	290,69116 3473,84218	1 11	290,69116 315,80383	0.92	0.3580
19	CE ERROR	627,56907 6180,05676	2 22	313,78454 280,91167	1.12	0.3451
20	DCE ERROR	372,37715 13254,75890	2 22	186,18857 602,48904	0.31	0.7373
21	FE ERROR	3775,32421 3995,17738	1 11	3775,32421 363,19794	10.39	0.0081
22	DPE ERROR	132,74110 8212,55619	1 11	132,74110 746,59602	0.18	0.6814
23	CPE ERROR	470,61734 13452,60961	2 22	235,30867 611,48225	0.38	0.6851
24	DCPE ERROR	459,80318 14670,43286	2 22	229,90159 666,83786	0.34	0.7121
25	RE ERROR	2799,07142 3427,57698	1 11	2799,07142 311,59791	8.98	0.0121
26	DRE ERROR	158,25010 1594,78848	1 11	158,25010 144,98077	1.09	0.3185
27	CRE ERROR	818,42084 9424,26148	2 22	409,21042 428,37552	0.96	0.4001
28	DCRE ERROR	526,37750 13787,13625	2 22	263,18875 626,68801	0.42	0.6622
29	PRE ERROR	1424,84230 5189,46979	1 11	1424,84230 471,76998	3.02	0.1101
30	DPRE ERROR	383,84316 6508,20298	1 11	383,84316 591,65482	0.65	0.4376
31	CPRE ERROR	1225,18953 11162,93893	2 22	612,59476 507,40631	1.21	0.3181
32	DCPRE ERROR	207,52737 14412,46995	2 22	103,76369 655,11227	0.16	0.8545

Alert Level

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	1390.63114	1	1390.63114	67.03	0.0000
	ERROR	228.22005	11	20.74728		
2	TYPE	613.41383	2	306.70692	12.85	0.0002
	ERROR	525.03206	22	23.86509		

Event Types

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	5014.55895	1	5014.55895	131.02	0.0000
	ERROR	420.99793	11	38.27254		
2	TYPE	1759.85096	8	219.98137	6.57	0.0000
	ERROR	2945.56061	88	33.47228		

Advisory Events

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	5857.45694	1	5857.45694	108.45	0.0000
	ERROR	594.14320	11	54.01302		
2	TYPE	481.61118	4	120.40279	2.01	0.1092
	ERROR	2632.12881	44	59.82111		

Caution Events

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	337.08960	1	337.08960	79.10	0.0000
	ERROR	46.87879	11	4.26171		
2	TYPE	7.90875	2	3.95437	1.20	0.3193
	ERROR	72.30838	22	3.28674		

Completion Time

Primary Variables

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	500927.75378	1	500927.75378	214.24	0.0000
	ERROR	25720.15997	11	2338.19636		
2	DIS	7007.57365	1	7007.57365	21.15	0.0008
	ERROR	3644.82865	11	331.34806		
3	CON	4361.14803	2	2180.57401	3.55	0.0461
	ERROR	13511.33673	22	614.15167		
4	DC	2878.25091	2	1439.12546	1.87	0.1784
	ERROR	16969.00362	22	771.31835		
5	PRO	32672.31039	1	32672.31039	22.87	0.0006
	ERROR	15716.51130	11	1428.77375		
6	DP	1000.75744	1	1000.75744	1.09	0.3189
	ERROR	10099.27190	11	918.11563		
7	CP	2961.24911	2	1480.62456	1.48	0.2496
	ERROR	22021.57725	22	1000.98078		
8	DCP	1069.15718	2	534.57859	0.77	0.4771
	ERROR	15363.81542	22	698.35525		
9	REP	573.34303	1	573.34303	0.72	0.4127
	ERROR	8701.05767	11	791.00524		
10	DR	63.00394	1	63.00394	0.29	0.5985
	ERROR	2356.89681	11	214.26335		
11	CR	1562.61865	2	781.30932	2.16	0.1387
	ERROR	7942.77051	22	361.03502		
12	DCR	158.61231	2	79.30616	0.06	0.9453
	ERROR	30940.90813	22	1406.40492		
13	PR	9.11184	1	9.11184	0.02	0.8982
	ERROR	5842.37308	11	531.12483		
14	DPR	0.00944	1	0.00944	0.00	0.9974
	ERROR	9384.09282	11	853.09935		
15	CFR	3435.13618	2	1717.56809	2.04	0.1542
	ERROR	18542.50979	22	842.84135		

16	DCPR	1349.54978	2	674.77489	1.03	0.3751
	ERROR	14476.08533	22	658.00388		
17	EVE	84.05988	1	84.05988	0.09	0.7648
	ERROR	9834.15499	11	894.01409		
18	DE	276.25768	1	276.25768	0.39	0.5433
	ERROR	7725.12305	11	702.28391		
19	CE	691.02258	2	345.51129	0.38	0.6885
	ERROR	20025.42143	22	910.24643		
20	DCE	3454.15789	2	1727.07894	2.46	0.1082
	ERROR	15416.29870	22	700.74085		
21	PE	34.85622	1	34.85622	0.09	0.7698
	ERROR	4261.39525	11	387.39957		
22	DPE	192.03497	1	192.03497	0.43	0.5260
	ERROR	4925.75624	11	447.79602		
23	CPE	1207.13110	2	603.56555	0.64	0.5385
	ERROR	20855.61957	22	947.98271		
24	DCPE	1226.73089	2	613.36544	1.45	0.2556
	ERROR	9290.00943	22	422.27316		
25	RE	1747.49082	1	1747.49082	2.58	0.1363
	ERROR	7441.04551	11	676.45868		
26	DRE	262.68036	1	262.68036	0.46	0.5113
	ERROR	6270.55309	11	570.05028		
27	CRE	1493.22055	2	746.61027	1.17	0.3293
	ERROR	14054.78199	22	638.85373		
28	DCRE	2367.16949	2	1183.58475	1.03	0.3741
	ERROR	25313.40472	22	1150.60931		
29	PRE	229.98731	1	229.98731	0.66	0.4321
	ERROR	3804.47242	11	345.86113		
30	DPRE	311.99628	1	311.99628	0.25	0.6239
	ERROR	13485.75572	11	1225.97779		
31	CPRE	502.93462	2	251.46731	0.25	0.7793
	ERROR	21939.96394	22	997.27109		
32	DCPRE	2974.66321	2	1487.33160	1.91	0.1712
	ERROR	17090.53678	22	776.84258		

Alert Level

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	43573.57025	1	43573.57025	157.32	0.0000
	ERROR	3046.63182	11	276.96653		
2	TYPE	1123.90092	2	561.95046	6.24	0.0071
	ERROR	1979.76656	22	89.98939		

Event Types

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	83767.56351	1	83767.56351	334.48	0.0000
	ERROR	2754.86460	11	250.44224		
2	TYPE	14084.75040	8	1760.59380	10.04	0.0000
	ERROR	15427.93308	88	175.31742		

Advisory Events

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	31171.61565	1	31171.61565	175.02	0.0000
	ERROR	1959.12870	11	178.10261		
2	TYPE	6816.46689	4	1704.11672	14.54	0.0000
	ERROR	5158.15565	44	117.23081		

Caution Events

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	36729.21120	1	36729.21120	157.82	0.0000
	ERROR	2560.02686	11	232.72971		
2	TYPE	3100.05540	2	1550.02770	4.82	0.0183
	ERROR	7071.37160	22	321.42598		

Discrete Actions

Primary Variables

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN ERROR	5890.56250 130.93750	1 11	5890.56250 11.90341	494.86	0.0000
2	DIS ERROR	1.56250 85.02083	1 11	1.56250 7.72917	0.20	0.6617
3	CON ERROR	3.57292 72.67708	2 22	1.78646 3.30350	0.54	0.5898
4	DC ERROR	8.09375 170.57292	2 22	4.04688 7.75331	0.52	0.6005
5	PRO ERROR	68.06250 58.10417	1 11	68.06250 5.28220	12.89	0.0042
6	DP ERROR	11.67361 57.74306	1 11	11.67361 5.24937	2.22	0.1640
7	CP ERROR	37.07292 165.01042	2 22	18.53646 7.50047	2.47	0.1076
8	DCP ERROR	8.27431 77.55903	2 22	4.13715 3.52541	1.17	0.3279
9	REP ERROR	10.02778 204.97222	1 11	10.02778 18.63384	0.54	0.4785
10	DR ERROR	9.00000 50.75000	1 11	9.00000 4.61364	1.95	0.1900
11	CR ERROR	0.60764 207.89236	2 22	0.30382 9.44965	0.03	0.9684
12	DCR ERROR	11.32292 151.42708	2 22	5.66146 6.88305	0.82	0.4524
13	PR ERROR	0.02778 25.97222	1 11	0.02778 2.36111	0.01	0.9156
14	DPR ERROR	12.25000 83.66667	1 11	12.25000 7.60606	1.61	0.2306
15	CPR ERROR	3.06597 125.43403	2 22	1.53299 5.70155	0.27	0.7667

16	DCPR ERROR	22.07292 116.01042	2 22	11.03646 5.27320	2.09	0.1472
17	EVE ERROR	1.00000 78.58333	1 11	1.00000 7.14394	0.14	0.7154
18	DE ERROR	16.00000 89.00000	1 11	16.00000 8.09091	1.98	0.1873
19	CE ERROR	15.32292 142.09375	2 22	7.66146 6.45881	1.19	0.3242
20	DCE ERROR	21.26042 96.23958	2 22	10.63021 4.37453	2.43	0.1113
21	PE ERROR	4.00000 104.08333	1 11	4.00000 9.46212	0.42	0.5289
22	DPE ERROR	12.25000 73.41667	1 11	12.25000 6.67424	1.84	0.2027
23	CPE ERROR	27.19792 120.71875	2 22	13.59896 5.48722	2.48	0.1070
24	DCPE ERROR	14.84375 106.48958	2 22	7.42187 4.84044	1.53	0.2380
25	RE ERROR	45.56250 72.18750	1 11	45.56250 6.56250	6.94	0.0232
26	DRE ERROR	10.56250 65.93750	1 11	10.56250 5.99432	1.76	0.2113
27	CRE ERROR	11.38542 188.11458	2 22	5.69271 8.55066	0.67	0.5239
28	DCRE ERROR	55.90625 188.84375	2 22	27.95313 8.58381	3.26	0.0577
29	PRE ERROR	0.06250 83.85417	1 11	0.06250 7.62311	0.01	0.9295
30	DPRE ERROR	1.56250 71.60417	1 11	1.56250 6.50947	0.24	0.6338
31	CPRE ERROR	3.96875 197.86458	2 22	1.98438 8.99384	0.22	0.8038
32	DCPRE ERROR	15.03125 128.05208	2 22	7.51563 5.82055	1.29	0.2950

Alert Level

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	434.49317	1	434.49317	199.02	0.0000
	ERROR	24.01495	11	2.18318		
2	TYPE	17.18649	2	8.59324	19.91	0.0000
	ERROR	9.49742	22	0.43170		

Event Types

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	1228.91882	1	1228.91882	310.05	0.0000
	ERROR	43.55997	11	3.95355		
2	TYPE	201.12207	8	25.14026	14.82	0.0000
	ERROR	149.29067	68	1.69648		

Advisory Events

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	488.47355	1	488.47355	149.82	0.0000
	ERROR	35.86334	11	3.26030		
2	TYPE	66.19286	4	16.54822	17.90	0.0000
	ERROR	40.68601	44	0.92468		

Caution Events

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	567.13835	1	567.13835	344.08	0.0000
	ERROR	18.13127	11	1.64830		
2	TYPE	98.00684	2	49.00342	13.37	0.0002
	ERROR	80.65479	22	3.66613		

Heading RMS Error

Primary Variables

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	796.58006	1	796.58006	1537.27	0.0000
	ERROR	5.69996	11	0.51818		
2	DIS	1.41115	1	1.41115	7.64	0.0184
	ERROR	2.03046	11	0.18459		
3	CON	0.26546	2	0.13273	0.88	0.4280
	ERROR	3.30971	22	0.15044		
4	DC	0.35406	2	0.17703	0.60	0.5599
	ERROR	6.53901	22	0.29723		
5	PRO	0.31313	1	0.31313	0.82	0.3836
	ERROR	4.18331	11	0.38030		
6	DP	0.39533	1	0.39533	2.61	0.1347
	ERROR	1.66796	11	0.15163		
7	CP	0.45728	2	0.22864	0.66	0.5285
	ERROR	7.66037	22	0.34820		
8	DCP	0.63432	2	0.31716	1.70	0.2057
	ERROR	4.10321	22	0.18651		
9	REP	0.08483	1	0.08483	0.38	0.5479
	ERROR	2.42797	11	0.22072		
10	DR	2.02232	1	2.02232	6.09	0.0312
	ERROR	3.65253	11	0.33205		
11	CR	2.25065	2	1.12532	6.62	0.0056
	ERROR	3.74075	22	0.17003		
12	DCR	0.15148	2	0.07574	0.34	0.7121
	ERROR	4.83129	22	0.21960		
13	PR	0.37976	1	0.37976	1.51	0.2446
	ERROR	2.76430	11	0.25130		
14	DPR	0.00029	1	0.00029	0.00	0.9655
	ERROR	1.63559	11	0.14869		
15	CPR	0.37671	2	0.18835	0.53	0.5973
	ERROR	7.85362	22	0.35698		

16	DCPR ERROR	1.26901 3.89158	2 22	0.63451 0.17689	3.59	0.0448
17	EVE ERROR	0.89855 2.92009	1 11	0.89855 0.26546	3.38	0.0929
18	DE ERROR	0.45282 3.55501	1 11	0.45282 0.32318	1.40	0.2615
19	CE ERROR	0.56185 5.38349	2 22	0.28092 0.24470	1.15	0.3356
20	DCE ERROR	0.37178 3.12634	2 22	0.18589 0.14211	1.31	0.2906
21	FE ERROR	0.14919 3.07379	1 11	0.14919 0.27944	0.53	0.4802
22	DPE ERROR	0.78988 2.00484	1 11	0.78988 0.18226	4.33	0.0615
23	CPE ERROR	0.19854 1.63074	2 22	0.09927 0.07412	1.34	0.2826
24	DCPE ERROR	0.19560 3.39498	2 22	0.09780 0.15432	0.63	0.5400
25	RE ERROR	1.06004 2.15298	1 11	1.06004 0.19573	5.42	0.0401
26	DRE ERROR	0.00439 1.32193	1 11	0.00439 0.12018	0.04	0.8519
27	CRE ERROR	0.18763 4.53682	2 22	0.09381 0.20622	0.45	0.6403
28	DCRE ERROR	2.17994 5.06783	2 22	1.08997 0.23036	4.73	0.0195
29	PRE ERROR	1.24044 2.17902	1 11	1.24044 0.19809	6.26	0.0294
30	DPRE ERROR	0.00184 2.30648	1 11	0.00184 0.20968	0.01	0.9270
31	CPRE ERROR	0.35000 4.58972	2 22	0.17500 0.20862	0.84	0.4456
32	DCPRE ERROR	0.45619 4.49793	2 22	0.22810 0.20445	1.12	0.3455

Alert Level

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
	MEAN	43.50941	1	43.50941	950.15	0.0000
1	ERROR	0.50371	11	0.04579		
	TYPE	0.37985	2	0.18993	2.97	0.0724
2	ERROR	1.40905	22	0.06405		

Event Types

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
	MEAN	128.67039	1	128.67039	1030.09	0.0000
1	ERROR	1.37403	11	0.12491		
	TYPE	0.40295	8	0.05037	1.16	0.3306
2	ERROR	3.81114	88	0.04331		

Vertical Speed RMS Error

Primary Variables

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN ERROR	25682.59960 560.16745	1 11	25682.59960 50.92431	504.33	0.0000
2	DIS ERROR	9.15819 95.85491	1 11	9.15819 8.71408	1.05	0.3273
3	CON ERROR	32.96426 282.16402	2 22	16.48213 12.82564	1.29	0.2966
4	DC ERROR	48.95214 472.19964	2 22	24.47607 21.46362	1.14	0.3379
5	PRO ERROR	9.32030 253.64652	1 11	9.32030 23.05877	0.40	0.5379
6	DP ERROR	18.37908 121.16724	1 11	18.37908 11.01520	1.67	0.2229
7	CP ERROR	41.45183 482.60437	2 22	20.72592 21.93656	0.94	0.4040
8	DCP ERROR	19.74835 219.63985	2 22	9.87418 9.98363	0.99	0.3879
9	REP ERROR	3.46425 152.74725	1 11	3.46425 13.88611	0.25	0.6273
10	DR ERROR	36.60754 175.33650	1 11	36.60754 15.93968	2.30	0.1579
11	CR ERROR	2.82336 264.94908	2 22	1.41168 12.04309	0.12	0.8899
12	DCR ERROR	6.86327 192.46242	2 22	3.43163 8.74829	0.39	0.6802
13	PR ERROR	27.24405 181.42872	1 11	27.24405 16.49352	1.65	0.2251
14	DFR ERROR	0.40481 29.57874	1 11	0.40481 2.68898	0.15	0.7054
15	CFR ERROR	0.75415 231.56365	2 22	0.37708 10.52562	0.04	0.9649

16	DCPR ERROR	12.86391 348.25762	2 22	6.43195 15.82989	0.41	0.6710
17	EVE ERROR	135.90702 353.36541	1 11	135.90702 32.12413	4.23	0.0642
18	DE ERROR	10.27470 100.95108	1 11	10.27470 9.17737	1.12	0.3127
19	CE ERROR	8.18424 131.34540	2 22	4.09212 5.97025	0.69	0.5143
20	DCE ERROR	8.03007 166.07343	2 22	4.01503 7.54879	0.53	0.5949
21	FE ERROR	0.19988 152.07818	1 11	0.19988 13.82529	0.01	0.9065
22	DPE ERROR	13.62533 84.66280	1 11	13.62533 7.69662	1.77	0.2103
23	CPE ERROR	2.21231 301.72016	2 22	1.10616 13.71455	0.08	0.9228
24	DCPE ERROR	36.33055 273.99195	2 22	18.16528 12.45418	1.46	0.2542
25	RE ERROR	2.71288 96.96172	1 11	2.71288 8.81470	0.31	0.5902
26	DRE ERROR	27.70706 216.27776	1 11	27.70706 19.66161	1.41	0.2602
27	CRE ERROR	2.07231 218.12780	2 22	1.03616 9.91490	0.10	0.9012
28	DCRE ERROR	3.65869 278.58751	2 22	1.82934 12.66307	0.14	0.8663
29	PRE ERROR	0.02933 84.41414	1 11	0.02933 7.67401	0.00	0.9518
30	DPRE ERROR	6.58564 152.86153	1 11	6.58564 13.89650	0.47	0.5055
31	CPRE ERROR	14.68658 158.03852	2 22	7.34329 7.18357	1.02	0.3763
32	DCPRE ERROR	7.39940 201.75530	2 22	3.69970 9.17070	0.40	0.6729

Alert Level

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	2688.21509	1	2688.21509	118.71	0.0000
	ERROR	249.09430	11	22.64494		
2	TYPE	28.42152	2	14.21076	5.17	0.0145
	ERROR	60.50009	22	2.75000		

Event Types

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	6419.50022	1	6419.50022	126.18	0.0000
	ERROR	559.64953	11	50.87723		
2	TYPE	195.02563	8	24.37820	3.53	0.0014
	ERROR	606.99455	88	6.89767		

Advisory Events

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	488.47355	1	488.47355	149.82	0.0000
	ERROR	35.86334	11	3.26030		
2	TYPE	66.19286	4	16.54822	17.90	0.0000
	ERROR	40.68601	44	0.92468		

Caution Events

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	567.13835	1	567.13835	344.08	0.0000
	ERROR	18.13127	11	1.64830		
2	TYPE	98.00684	2	49.00342	13.37	0.0002
	ERROR	80.65479	22	3.66613		

Airspeed RMS Error

Primary Variables

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN ERROR	1201.83557 74.23933	1 11	1201.83557 6.74903	178.08	0.0000
2	DIS ERROR	0.04375 8.52280	1 11	0.04375 0.77480	0.06	0.8165
3	CON ERROR	2.11318 7.01534	2 22	1.05659 0.31888	3.31	0.0552
4	IC ERROR	3.27016 28.35016	2 22	1.63508 1.28864	1.27	0.3009
5	PRO ERROR	1.46208 18.82035	1 11	1.46208 1.71094	0.85	0.3751
6	DP ERROR	0.02176 4.55489	1 11	0.02176 0.41408	0.05	0.8229
7	CP ERROR	0.20154 32.12351	2 22	0.10077 1.46016	0.07	0.9335
8	DCP ERROR	5.80568 16.07457	2 22	2.90284 0.73066	3.97	0.0336
9	REP ERROR	0.21545 4.78171	1 11	0.21545 0.43470	0.50	0.4961
10	DR ERROR	7.52131 10.10472	1 11	7.52131 0.91861	8.19	0.0155
11	CR ERROR	1.65765 13.02252	2 22	0.82882 0.59193	1.40	0.2677
12	DCR ERROR	1.24452 14.59665	2 22	0.62226 0.66348	0.94	0.4066
13	PR ERROR	2.93266 6.15385	1 11	2.93266 0.55944	5.24	0.0428
14	BPR ERROR	0.47266 4.68386	1 11	0.47266 0.42581	1.11	0.3147
15	CFR ERROR	1.13164 15.07240	2 22	0.56582 0.68511	0.83	0.4510

16	DCPR ERROR	3.85237 19.09899	2 22	1.92619 0.86814	2.22	0.1325
17	EVE ERROR	5.47950 11.71283	1 11	5.47950 1.06480	5.15	0.0444
18	DE ERROR	0.20175 10.54824	1 11	0.20175 0.95893	0.21	0.6554
19	CE ERROR	1.60775 20.06459	2 22	0.80388 0.91203	0.88	0.4283
20	DCE ERROR	2.40319 11.99896	2 22	1.20159 0.54541	2.20	0.1342
21	PE ERROR	1.91592 8.86902	1 11	1.91592 0.80627	2.38	0.1515
22	DPE ERROR	0.01085 3.71710	1 11	0.01085 0.33792	0.03	0.8610
23	CPE ERROR	0.85599 10.06033	2 22	0.42799 0.45729	0.94	0.4073
24	DCPE ERROR	1.44772 9.15190	2 22	0.72386 0.41600	1.74	0.1988
25	RE ERROR	0.04803 4.76545	1 11	0.04803 0.43322	0.11	0.7454
26	DRE ERROR	0.18562 4.93730	1 11	0.18562 0.44885	0.41	0.5334
27	CRE ERROR	2.68285 14.81221	2 22	1.34143 0.67328	1.99	0.1602
28	DCRE ERROR	2.51851 11.42139	2 22	1.25926 0.51915	2.43	0.1117
29	PRE ERROR	0.26095 3.18895	1 11	0.26095 0.28990	0.90	0.3631
30	DPRE ERROR	1.54795 7.23980	1 11	1.54795 0.65816	2.35	0.1534
31	CPRE ERROR	0.20455 13.34022	2 22	0.10228 0.60637	0.17	0.8459
32	DCPRE ERROR	2.19987 14.34309	2 22	1.09993 0.65196	1.69	0.2081

Alert Level

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	94.02211	1	94.02211	314.00	0.0000
	ERROR	3.29372	11	0.29943		
2	TYPE	0.27210	2	0.13605	1.28	0.2972
	ERROR	2.33355	22	0.10607		

Event Types

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	248.21468	1	248.21468	240.75	0.0000
	ERROR	11.34116	11	1.03101		
2	TYPE	1.87075	8	0.23384	1.24	0.2837
	ERROR	16.54810	88	0.18805		

Control Activity

Primary Variables

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	406512.50694	1	406512.50694	212.65	0.0000
	ERROR	21028.61806	11	1911.69255		
2	DIS	35.00694	1	35.00694	0.14	0.7169
	ERROR	2781.61806	11	252.87437		
3	CON	760.01389	2	380.00694	0.70	0.5060
	ERROR	11896.61111	22	540.75505		
4	DC	951.26389	2	475.63194	2.17	0.1376
	ERROR	4814.61111	22	218.84596		
5	PRO	1201.77778	1	1201.77778	1.39	0.2630
	ERROR	9499.26389	11	863.56944		
6	DP	240.25000	1	240.25000	1.05	0.3266
	ERROR	2506.45833	11	227.85985		
7	CP	122.59722	2	61.29861	0.20	0.8165
	ERROR	6591.36111	22	299.60732		
8	DCP	75.54167	2	37.77083	0.12	0.8849
	ERROR	6755.50000	22	307.06818		
9	REP	6.25000	1	6.25000	0.03	0.8620
	ERROR	2170.79167	11	197.34470		
10	DR	152.11111	1	152.11111	0.57	0.4677
	ERROR	2956.93056	11	268.81187		
11	CR	141.29167	2	70.64583	0.30	0.7465
	ERROR	5245.16667	22	238.41667		
12	DCR	437.59722	2	218.79861	0.82	0.4546
	ERROR	5889.61111	22	267.70960		
13	PR	82.50694	1	82.50694	1.34	0.2714
	ERROR	676.78472	11	61.52588		
14	DPR	10.56250	1	10.56250	0.03	0.8589
	ERROR	3506.89583	11	318.80871		
15	CPR	179.18056	2	89.59028	0.76	0.4810
	ERROR	2604.27778	22	118.37626		

16	DCPR ERROR	285.79167 4333.25000	2 22	142.89583 196.96591	0.73	0.4953
17	EVE ERROR	6765.06250 1850.47917	1 11	6765.06250 168.22538	40.21	0.0001
18	DE ERROR	8.50694 1711.70139	1 11	8.50694 155.60922	0.05	0.8194
19	CE ERROR	348.29167 1794.91667	2 22	174.14583 81.58712	2.13	0.1422
20	DCE ERROR	178.84722 2533.94444	2 22	89.42361 115.17929	0.78	0.4723
21	PE ERROR	23.36111 2091.09722	1 11	23.36111 190.09975	0.12	0.7325
22	DPE ERROR	90.25000 1941.37500	1 11	90.25000 176.48964	0.51	0.4894
23	CPE ERROR	553.93056 4276.11111	2 22	276.96528 194.36869	1.42	0.2619
24	DCPE ERROR	289.04167 2623.08333	2 22	144.52083 119.23106	1.21	0.3167
25	RE ERROR	205.44444 1169.18056	1 11	205.44444 106.28914	1.93	0.1919
26	DRE ERROR	121.00000 1303.79167	1 11	121.00000 118.52652	1.02	0.3340
27	CRE ERROR	94.59722 3108.77778	2 22	47.29861 141.30808	0.33	0.7191
28	DCRE ERROR	187.79167 2450.66667	2 22	93.89583 111.39394	0.84	0.4439
29	PRE ERROR	351.56250 1783.97917	1 11	351.56250 162.17992	2.17	0.1690
30	DPRE ERROR	52.56250 1614.31250	1 11	52.56250 146.75568	0.36	0.5616
31	CPRE ERROR	613.04167 3322.16667	2 22	306.52083 151.00758	2.03	0.1552
32	DCPRE ERROR	489.12500 3724.00000	2 22	244.56250 169.27273	1.44	0.2573

Alert Level

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	28419.77843	1	28419.77843	197.20	0.0000
	ERROR	1585.30410	11	144.11855		
2	TYPE	369.70502	2	184.85251	16.78	0.0000
	ERROR	242.38149	22	11.01734		

Events Types

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	72575.17169	1	72575.17169	181.76	0.0000
	ERROR	4392.27779	11	399.29798		
2	TYPE	439.72965	8	54.96621	1.88	0.0728
	ERROR	2570.16373	88	29.20641		

Advisory Events

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	27036.62211	1	27036.62211	196.28	0.0000
	ERROR	1515.22932	11	137.74812		
2	TYPE	44.92951	2	22.46475	0.88	0.4285
	ERROR	561.01057	22	25.50048		

Caution Events

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN	39511.57617	1	39511.57617	161.63	0.0000
	ERROR	2689.00859	11	244.45533		
2	TYPE	193.31135	4	48.32784	1.29	0.2869
	ERROR	1642.95188	44	37.33982		

Workload Rating

	SOURCE	SUM OF SQUARES	DEGREES OF FREEDOM	MEAN SQUARE	F	TAIL PROBABILITY
1	MEAN ERROR	9004.82000 548.88667	1 11	9004.82000 49.89879	180.46	0.0000
2	DIS ERROR	59.40500 50.03500	1 11	59.40500 4.54864	13.06	0.0041
3	CON ERROR	28.95083 17.77250	2 22	14.47542 0.80784	17.92	0.0000
4	DC ERROR	44.06083 69.02917	2 22	22.03042 3.13769	7.02	0.0044
5	PRO ERROR	27.38000 117.72667	1 11	27.38000 10.70242	2.56	0.1380
6	DP ERROR	14.04500 53.19500	1 11	14.04500 4.83591	2.90	0.1164
7	CP ERROR	0.75250 105.87083	2 22	0.37625 4.81231	0.08	0.9250
8	DCF ERROR	5.64250 62.54750	2 22	2.82125 2.84307	0.99	0.3867
9	REP ERROR	10.88889 26.89111	1 11	10.88889 2.44465	4.45	0.0585
10	DR ERROR	1.22722 17.61944	1 11	1.22722 1.60177	0.77	0.4001
11	CR ERROR	1.66028 26.58972	2 22	0.83014 1.20862	0.69	0.5136
12	DCR ERROR	6.26028 41.02306	2 22	3.13014 1.86468	1.68	0.2097
13	PR ERROR	2.13556 12.64444	1 11	2.13556 1.14949	1.86	0.2001
14	DPR ERROR	0.12500 25.32167	1 11	0.12500 2.30197	0.05	0.8200
15	CPR ERROR	7.40194 49.54806	2 22	3.70097 2.25218	1.64	0.2162
16	DCPR ERROR	0.49083 49.49250	2 22	0.24542 2.24966	0.11	0.8971

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16. Abstract The System Status Display is an electronic display system which provides the crew with an enhanced capability for monitoring and managing the aircraft systems. A flight simulation in a fixed base cockpit simulator was used to evaluate alternative design concepts for this display system. The alternative concepts included pictorial versus alphanumeric text formats, multifunction versus dedicated controls, and integration of the procedures with the system status information versus paper checklists. Twelve pilots manually flew approach patterns with the different concepts. System malfunctions occurred which required the pilots to respond to the alert by reconfiguring the system. The pictorial display, the multifunction control interfaces collocated with the system display, and the procedures integrated with the status information all had shorter event processing times and lower subjective workloads.					
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